THE ANALCITE- AND LEUCITE-BASANITES OF EAST LOTHIAN.

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Thesis submitted for degree of Ph.D.

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October, 1939.

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Introduction.

Since the issue of the second edition (1910) of the Geological Survey Memoir on "The Geology of East Lothian", very little has been published on the detailed petrography of the basic intrusions of the area. T.C. Day (1925, 1932) in his descriptions of the numerous volcanic vents occurring along the coast from Weak Law to Whitberry Point, mentions the presence, in association with them, of several intrusions of 'monchiquitic' character. In most cases he gives a brief petrological description of the intrusives and in a few instances furnishes an analysis also. Two of these intrusions, occurring in the Car Vent and described by him as 'limburgitic' were re-examined by Balsillie (1936) who showed them to consist of leucite-basanite.

The basanitic intrusions of East Lothian occur in association with rocks of the Upper Old Red Sandstone and Lower Carboniferous (Calciferous Sandstone) periods. With the exception of the occurrences at Oldhamstocks and on the shore a mile east of Dunbar, they all lie in that part of the country lying to the north-west of the Southern Upland Fault. In this area the rocks of Upper Old Red Sandstone age are confined to a strip 1-2 miles in width occurring alongside the fault and bounded on the north-west side by the Dunbar-Gifford Fault. The Calciferous Sandstone rocks consist of two groups of sediments of lower Cementstone and upper Oil-Shale age respectively, separated by a thick pile of volcanic rocks. The lower group of sediments includes marl cementstone and sandstone and is separated from the lowest lava by a thick bed of ash. The upper group consists of shale, marl, and volcanic conglomerate. The volcanic series, which includes a few thin beds of ash, occurs in two well-marked lava-groups. The lower and more basic of these consists of basalts of Craiglockhart, Dunsapie, and Markle type, interspersed with flows of mugearite, the succession being, in general, one of decreasing basicity. An occurrence of kulaite is recorded at the base of the group in the southern part of the area. Two flows of a somewhat similar nature occur in a corresponding position in the North Berwick district and will be described in the sequel (p.114). The lavas of the upper group are mainly trachytic in composition. As the general dip is westerly, the lower and upper groups outcrop over the eastern and western parts of the area respectively. Volcanic vents are fairly numerous, especially along the coast from Weak Law to the Dunbar district. Isolated occurrences are recorded from several localities inland. Many of the intrusive stocks which are not seen associated with explosive detritus may yet represent the orifices of volcanoes.

Intrusive rocks genetically related to the lavas but tending to be more alkaline and richer in felspathoids, occur as plugs, sills, and laccoliths at various horizons. In addition to types which can be directly "matched" among the lavas and are therefore presumably contemporary with them, others such as phonolite, teschenite (including essexite), quartz-dolerite, and basanite are represented, and are, except phonolite, demonstrably later, in part at least, than the lavas. Before discussing the evidence for the age of the basanites, however, a brief description of the group as a whole will be given.

They occur as sills and plug-like bodies which are, roughly speaking, confined to the north and south fringes of the area indicated above. The majority, including most of the plugs are of small extent, many of the latter occurring in vents in association with tuff and agglomerate. Some of the sills, however, such as those at Limplum and Chesters reach considerable dimensions, the former having an outcrop extending for about 3 miles. Blocks of basanite from a few vents which contain no visible intrusion will also be described in view of their importance as evidence for the age of the group.

As a group, these rocks show certain well-marked characteristics which are enumerated by Bailey in the

Memoir. To summarise, they are, when fresh, invariably black compact rocks, typically fine-grained, but in the larger sills locally coarser. Where exposed in quarries or on the shore, the sills show well-developed columnar jointing. The plugs are also well jointed, platy parting being developed near margins. A characteristic feature is the presence of analcite in crystals, usually about 2-3 mm. in diameter, having poecilitic relations to the other minerals. They appear on the freshly broken surface as small rounded areas, each of which is seen to have a lustre, as of a cleavage face, when light reflected from it catches the eye. On the weathered surface they appear as light spots which may be distinct or may fuse together to a greater or less extent. The analcite crystals thus simulate the habit of phenocrysts and the structure is therefore known as pseudoporphyritic. Microphenocrysts of olivine are invariably present usually in considerable numbers and often accompanied by scattered large phenocrysts of the same mineral. Though sometimes fairly fresh they are more often replaced by red or dark green products. Porphyritic augite is often present, usually in subordinate amount to the olivine. In microsection, the crystals of this mineral usually show colour-zoning from green chrome-diopside or pale purplish titanaugite interiors to deeper purple margins. Seive-structure, produced by a vermiculate resorption of the interior zone, is typical. The groundmass consists in all cases of granular titanaugite and magnetite, plagioclase laths and accessory apatite, the proportions varying in the different types. Other minerals such as nepheline, orthoclase, albite, biotite and hornblende may be present in important or minor amount. In some occurrences sporadic large crystals of augite may be detected. The presence also of peridotitic and gabbroitic nodules is discussed at length by Bailey (ibid).

As regards the age of these intrusions, there is a lack of conclusive evidence. Several, notably the Black Rocks, Eyebroughy and West Fenton sills are seen to be intruded into sediments overlying the trachyte lavas. The presence of extrusive equivalents of the basanites has not so far been proved. One occurrence, that on the shore a mile east of Dunbar, has been suggested as such by Clough in the Memoir. In a later section (p.96) evidence will be reviewed which at least casts doubt on this interpretation.

The intimate association of basanite intrusions with volcanic vents is a potential source of evidence for their age. The following points are significant in this connection. The vents at Partan Craig, the Yellow Man, Gin Head, and the Car, all contain numerous blocks of basanite. These vents and the others occurring along the coast, contain, according to Day, no recognisable blocks of any rocks other than those of Calciferous Sandstone age, except in one isolated instance of a doubtful coral limestone in the Gin Head vent. In a few vents trachytic agglomerate occurs, indicating a late Calciferous Sandstone age at least for the final activity.

Dykes of sediment of Calciferous Sandstone facies filling earthquake or shrinkage fissures are reported by Day and also by A.G. MacGregor (1936) from several vents east of North Berwick. Particularly good examples are seen immediately to east and west of the Yellow Man Vent. The interpretation as such of certain dyke-like inclusions of sedimentary material in the basanite of the Leithies is open to doubt. They are unstratified and some at least suggest "rolled out" xenoliths.

The implications are, then, that intrusion of basanite was in part contemporary with explosive volcanic activity, and that in some vents at least, activity had ceased before the end of Calciferous Sandstone times. Undisturbed vent plugs however, testify to the continuation of the intrusive phase after explosive activity had ceased. The age of these later intrusions is doubtful. The fact that basanites are not known to occur intruded into sediments of later age than the Calciferous Sandstone period is no guarantee that they did not at one time invade higher horizons. They show petrological affinities to the basalts of Hillhouse type occurring in the Burntisland and Bathgate districts, and which were extruded between Upper

Calciferous Sandstone and Upper Carboniferous Limestone times. (Falconer 1906, and Allan 1924). Tyrell (1923) points out that - "The monchiquites and analcite basalts of East Lothian are remarkably similar to the rocks intrusive into Permian volcanic vents of Fife and Ayrshire. It is at least a probability therefore, that they are really connected with late-Carboniferous or Permian vulcanicity."

PETROLOGY OF THE BASANITES.

In the Memoir, Bailey, referring to the fine-grained basic intrusions of East Lothian, states that - "Under the microscope most of these intrusions show themselves to be members of a rock series, in Brögger's sense, including every gradation from augite-monchiquite to basalt. This continuous series has, however, been arbitrarily divided into two groups." The latter comprise (a) "Monchiquites together with doubtful nepheline-basalts" and (b) "Fine-grained porphyritic olivine-analcite basalts."

Sections cut from the majority of the known intrusion show that Bailey's suggestion of a continuous series, although it indicates the general trend of the variation, is not quite comprehensive enough to give a true conception of the relationships involved. A serial gradation exists in the variation of the amount of augite from basaltic to lamprophyric proportions and the corresponding decrease in felspar. Complications are however introduced when the distribution and habit of analcite are considered.

In a few intrusions, analcite occurs in minor quantity only. In these cases the amounts of felspar and augite are of the "basaltic" order, enabling the rocks to be classified among the microporphyritic basalts, of the Dalmeny type in particular. Other instances occur in which the general characters of the rock, and in particular, the amount and habit of the analcite, are strongly suggestive of the finer-grained or 'basaltic' teschenites. Except for a few glassy rocks whose relations will be considered separately, the rest of the intrusions contain, in each case, sufficient primary analcite to permit of their classification as basanites.

The pseudoporphyritic habit of the analcite is peculiar to these rocks as a group, being developed to a greater or less degree of distinctness in each one of them. Among them, also, the proportions of augite and felspar vary in the manner indicated above. A natural division occurs however at approximately the same point as that suggested by Bailey. It is found that certain of the more lamprophyric rocks (melabasanites) possess common characteristics, apart from their high augite content, which render them easily distinguishable from the other basanites and melabasanites. They will be referred to as 'the Chesters type' after the locality in which they occur in best development. Those basanitic rocks which contain leucite will also be treated as a separate division. Three main divisions may therefore be distinguished:

A. Analcite-melabasanites of Chesters type.

B. Analcite-basanites and other analcite-melabasanites.

C. Leucite-basanites, (including kulaites).

A. ANALCITE - MELABASANITES OF CHESTERS TYPE.

Rocks belonging to this type occur at the following localities:-

(a) Chesters, near Garvald, in the south part of the area; a sill in the Upper Old Red Sandstone.

(b) Stenton, close to the Dunbar-Gifford Fault, 4 miles north-east of Chesters; two plugs in the Basal Ash of the Volcanic Series.

(c) North Berwick; four small plugs in a vent on the Lecks shore, (pl.III); also a small plug in the Basal Ash near Swiney Craigs.

(d) The Leithies (pl.IV) on the shore 1 mile east of North Berwick; a small laccolith in the Basal Ash.

(e) Partan Craig, Yellow Man and Gin Head Vents (pl.IV) also on the shore east of North Berwick: blocks in the vent-agglomerates.

(a) Chesters Sill.

About a mile west of Garvald, and lying immediately to the south of Whitelaw Hill, an occurrence of basic intrusive rock gives rise to a broad elongated ridge stretching for about a mile in a south-easterly direction. The outcrop is half a mile in width at its north-west end and narrows to a furlong at its other extremity. The rock is in the form of a sill intruded into Upper Old Red Sandstone strata and dipping gently to the south-west, where it is truncated by a strike fault. The north-east margin is also determined by a fault - the Dunbar-Gifford Fault. At the northern end a deep fluvio-glacial channel cuts through the sill exposing the underlying sediments. Only the higher parts of the ridge are free from drift deposits, and cultivation has reduced the natural exposures to a few small outcrops on the sides of the east-west dry valley. Thus the study of the sill has been largely confined tomthe excellent artificial exposure of Chesters quarry which lies just south of this valley.

The rock in the quarry shows a well-developed columnar jointing perpendicular to the plane of the dip. The weathered surface is of a red-brown colour relieved by numerous lighter spots. These have rounded outlines, a diameter varying from an eighth to a quarter of an inch, and are usually closely crowded so that they more or less fuse together.

The freshly broken rock is dark, fine-grained and shows abundant microphenocrysts of olivine, sometimes fresh, more often altered to red or dark green products. Numerous small rounded areas with a faint lustre correspond in size and distribution to the light spots described above, and represent pseudoporphyritic analcite crystals. Scattered occurrences of small vesicles are seen to contain white or faintly reddish radiating fibrous zeolites.

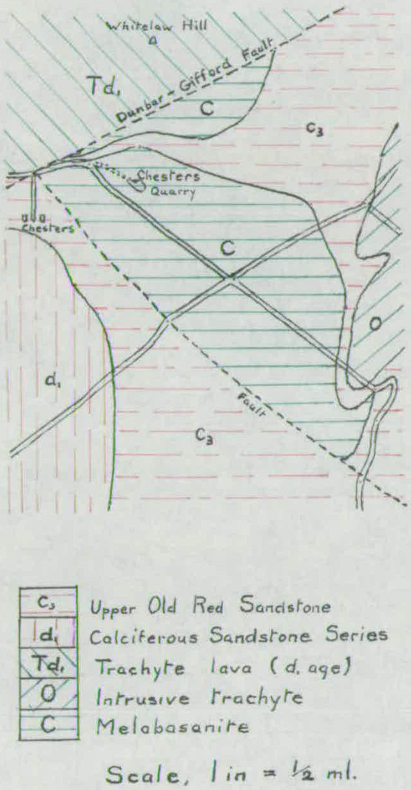
Locally, throughout the quarry, the rock is traversed by fine veinlets of dark orange-red crystalline material. Most of these veinlets are sub-parallel to the base of the sill. They vary in thickness from a few millimetres to a centimetre and show frequent branchings and discontinuities. Their habit suggests that they owe their origin to a concentration of residual liquor in irregular shrinkage partings developed in the rock before the groundmass has completely consolidated. Microscopic examination confirms this, and reveals also that the red colour is due to the abundance of zeolitic decomposition products of nepheline, stained orange-red by ferric matter.

In certain parts of the quarry the rock is seen to be completely permeated by this coloured vein-material.

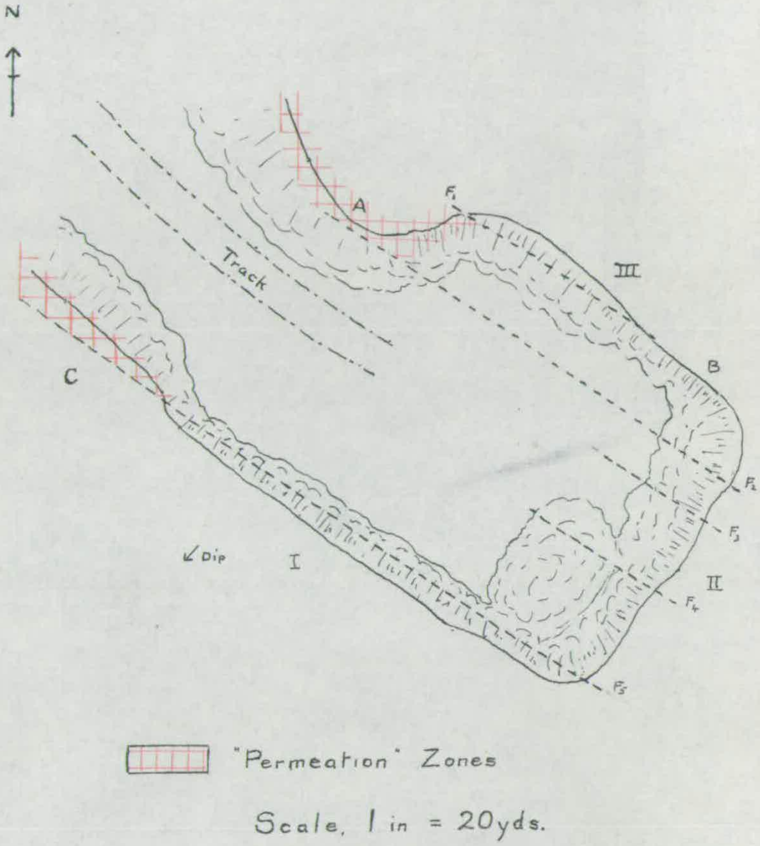
Various stages can be traced from the normal dark rock to a phase in which abundant phenocrysts of augite up to 8 mm. long can be seen embedded in the orange-red material as groundmass. These transition stages will be described in detail later. The permeation zônes consist chiefly of a rock which in its maih characters is about midway between the two extreme types just mentioned, and will be referred to in the sequel as the "medium phase". The coarse phase is seen in irregular schlieren, with a maximum observed width of three feet, occurring only in the medium phase.

In order to describe the distribution of the above phases with any exactness, some account of the quarry as a whole must first be given.

The sketch maps below give its position and lateral dimensions. The average height of the sides is about 25 feet. Sides I, II, and III have steep faces with columnar jointing showing on the last two. $F_1, F_2 ...$ are vertical planes of dislocation, one of which F_5 forms a large portion of Side I. They lie parallel to the main strike fault which bounds the sill on the south-west side. The distr ibution of the permeation phases seems to point to appreciable movement having taken place along these fault planes. At A, in a depth of 6 feet from the top



Chesters Sill.



Chesters Quarry.

of the quarry all phases are seen in a zone which is bounded laterally by F and F and appears to have a general westward dip. As it is truncated above, there is no means of estimating its original depth. No such modification is seen at B between the same faults. Again, at

C, all phases are seen in a zone which occupies the whole depth of the 25ft. cliff and which is bounded laterally by fault plane F . In the lower part of the cliff trans:ition stages to the normal rock are seen, suggesting that this zone does not extend much below this level. Again, the top is truncated by the quarry edge. The absence, except for a few veins, of the permeation phases in face II, where a continuation of zone C might have been expected, leads to the conclusion that these zones of abnormal rock do not always occur as layers parallel to the base of the sill, as suggested by zone A.

The Chesters Rock has been known to petrologists since the final decade of last century, chiefly through the writings of Hatch (1892) and Rosenbusch (1908). By By virtue of its isotropic ground-base it had been named limburgite (Hatch) and monchiquite (Rosenbusch) until E. B. Bailey in "The Geology of East Lothian" emphasised the presence of nepheline and classed it as a "doubtful nepheline basalt".

The following account of the "normal" rock necess:arily embodies previously published detail. The incor:poration of several new observations, however, may serve as an excuse for some repetition.

THE NORMAL ROCK, (Pl.I,1)

The thin section shows abundant microphenocrysts of olivine and a few of augite. Occasional glomero-porphyritic aggregates of augite occur and also olivine-augite intergrowths. The olivines are well-formed crystals usually just under 1 mm. long. Occasionally they are quite fresh but are more often seen in various stages of alteration to chloritic minerals and limonite. The pyroxene is the familiar purplish titanaugite of the Carbo-Permian Igneous Province. The phenocrysts have paler centres and show "seive structure" or corrosion porosity due to magmatic resorption.

The groundmass consists of abundant small prisms of purplish titanaugite together with considerably fewer magnetite grains of similar or slightly larger size. A few small flakes of biotite are present. Apatite occurs as prominent, frequently skeletal prisms, often ½ mm. long and enclosing sub-ophitically augite and magnetite grains.

The interstices are occupied by felspar, a little nepheline and much analcite. The felspar is a plagioclase usually of a composition about labradorite but occasionally more sodic. It is sometimes seen to be bordered by albite, and occurs as somewhat elongated plates up to 1 mm. long, enclosing poecilitically the augite magnetite and apatite of the groundmass. A little albite is present also, usually associated with the nepheline. Occasionally some small plates of orthoclase may be observed. The nepheline occurs in small prisms seen in varying stages of decay to reddish-stained zeolites. It appears to have crystallised after the basic plagioclase but before or along with the albite and before the analcite. The remainder of the groundmass, about two-thirds is occupied by analcite and small patches of zeolite of the same kind that is derived from the decomposition of nepheline. The bulk of the analcite is clear and yellowish in colour and forms rounded areas separated, to some extent, by cloudy analcite and zeolites, and enclosing poecilitically all the other groundmass minerals. These analcite areas evidently correspond to the lustrous spots seen on the hand specimen and so may be recognised as individual analcite crystals. In the slide, as in the hand specimen, they are seen to be crowded together, making their character less obvious at first sight. The analcite contains inclusions of fine apatite needles and, locally, groups of radiating slender fibrils of a black substance, presumably an iron oxide. With similar habit, and sometimes intermingled with these, occur clusters of fine, elongated, branching flakes of brown amphibole. Small ragged flakes of red brown biotite are also seen.

The normal rock in the quarry does not show much variation in texture. Specimens from the detached outcrop to the north of the dry valley showed a considerably finer grain, as might be expected from their inferred position nearer the base of the sill. No veins were detected here; otherwise the petrology of the rock is similar to that in the quarry.

Veins, (Pl.I,4,5,6)

In the description of the field characters of the rock, mention was made of the veinlets which can be detected in varying numbers over most of the quarry exposure. They are not regularly parallel to the base of the sill, although this is their general trend, but are frequently seen to branch and curve into vertical planes as if their formation had been influenced by horizontal as well as vertical tensions.

The mineral content of the veins may be briefly summarised as follows. A varying amount of titanaugite, titanomagnetite, and plagioclase occurs, all in abnormally large or "pegmatitic" development. In this category also may be placed some brown hornblende and early-formed apatite. These minerals are associated with a groundmass which forms the main bulk of the vein and consists of nepheline, alkali felspar, analcite, and zeolites with apatite and small amounts of pyroxene, amphibole, and biotite as accessories.

The titanaugite occurs in scattered, well-formed prisms up to 2.5 mm. long and of a deeper purple colour than the pyroxene of the adjacent normal rock, indicating a higher content of titanium. Concentric colour zones are absent but hour-glass zoning and lamellar twinning are common. The titanomagnetite is seen in crystals which frequently exceed .5 mm. in diameter and sometimes show skeletal development. On the sides of the vein the augite and magnetite of the groundmass of the normal rock occur as individuals of larger size, and the crystals of these minerals occurring in the vein may be seen to be "rooted" in the rock groundmass. Similarly the plagioclase crystals are sometimes"shared" by rock and vein. A few chloritic pseudomorphs after olivine occur in the vein near the margins. They probably represent crystals separated from the normal rock during the process of disruption. The brown hornblende occurs in narrow blades sometimes reaching 2 mm. in length and is usually completely replaced by bright green chlorite. Both augite and magnetite enclose stout prisms of apatite which frequently exceed 1 mm. in length and typically show skeletal development. The plagioclase occurs in tabular crystals sometimes reaching a length of 1.5 mm. Their composition varies from labradorite to oligoclase and they are frequently seen to be bordered by albite. They show replacement by analcite along cracks and cleavages.

The groundmass of the vein contains a large proportion of nepheline, occurring in short prisms up to $\frac{1}{4}$ mm. in diameter. They may be euhedral or may show skeletal intergrowths with albite and also inclusions of skeletal pyroxene. These characteristics of the nepheline will be discussed more fully in the next section (p.33). The nepheline prisms may be seen enclosed in the oligoclase felspars and in the sodic borders of the more calcic plagioclases. It shows various stages of decomposition to zeolites whose reddish staining is responsible for the for the orange-red colour which characterises the veins in hand specimen. Small plates of albite occur interstitially to the nepheline, sometimes intergrown with it. Abundant small, slender laths of orthoclase are present, simply_twinned and occurring typically in radiating clusters. The veins are notable for a relatively high concentration of apatite and in addition to the larger prisms of this mineral mentioned above abundant smaller prisms and needles occur throughout the groundmass. Small ragged flakes of brown biotite are present and also pale greenish or purplish augite typically in bundles of parallel or radially divergent skeletal rods. A few small imperfect prisms of brown-green amphibole and also some slender rods of ilmenite were observed.

An important consituent of the groundmass is clear yellowish analcite which occupies approximately the same bulk as the material just described. It has a refractive index of 1.491 and occurs in masses which have mammillated outlines and apparently consist of accumulations of rounded individuals, with an average diameter of about ½ mm. The boundaries of these within the mass are sometimes marked by lines of cloudiness and darker colour, and each one contains, typically, radially arranged inclusions. By analogy with the rounded individuals occurring in the groundmass of the rock, each of these probably represents a distinct crystal of analcite. The latter mineral appears to have replaced the nepheline-alkali felspar groundmass as it contains relics such as corroded nepheline prisms and bundles of pyroxene rods with interstitial nepheline, albite, and zeolites. The analcite is characterised by the peculiar habit of its inclusions of ilmenite, brown hornblende, and pale green aegirine-augite. Each of these minerals is developed in numerous elongated slender individuals which are usually radially arranged in the rounded components of the analcite mass. Ilmenite is most abundant, occurring in fibrils which sometimes appear bent and twisted near the periphery of the rounded section. The hornblende occurs in thin ragged laths which assume a parallel, more often than a radiating, formation. The pyroxene is in fine rods which may also occur in either parallel or radiating arrangement.

Both felspathic and analcitic parts of the groundmass have been replaced in patches and vein-like streaks by late colourless cloudy analcite and also zeolites, the latter evidently representing decomposition products of nepheline which have migrated from the pseudomorphs of that mineral. In the felspathic groundmass these patches sometimes have tangentially arranged biotite flakes, thus producing the true ocellar structure.

The veins were apparently opened after the crystallisation of the olivine and most of the augite and magnetite of the rock groundmass. The concentration of early apatite in the veins indicates that this mineral had not yet crystallised in the parent rock. The late accumulation of phosphoric acid and titanium oxide characteristic of the basic alkaline rocks of the Carbo-Permian Igneous Province is manifested here in the abundance of late apatite, the precipitation of ilmenite from analcite, and the deeper purple colour of the large pyroxenes.

The clear yellowish analcite of the veins is identical in appearance and inclusions with the rounded crystals occurring in pseudoporphyritic habit in the groundmass of the rock. Also it must be distinguished from the later cloudy colourless analcite which contains no characteristic inclusions, has a lower refractive index than the yellowish mineral, and may be seen to replace the latter.

Permeation Phases.

In dealing with these abnormal types it is proposed first to describe the "medium" or average grade which represents the bulk of the development and then the coarse schlieren. The various transition stages will then be discussed.

Medium Grade, (Pl.I,2; Pl.II,3).

A brief summary of its features may be helpful in forming a general impression of this rock as seen in microsection. Fairly abundant microphenocrysts of olivine and augite are set in a groundmass of which half consists of augite and magnetite grains, the bulk of the remainder consisting of nepheline and its associated decomposition products. Some alkali felspar and cloudy analcite are also present and apatite forms a conspicuous accessory.

The olivine phenocrysts are larger than those of the normal rock, usually exceeding 1 mm. in length. They are sometimes fresh, more often decomposed to chlorites, bowlingite, and iron oxides. A little brown biotite is associated with the decomposition products.

The augite phenocrysts are of a similar average size and occur in similar quantity. A few megaphenocrysts exceeding 3 mms. in diameter occur and occasionally glomeroporphyritic aggregates and augite-olivine intergrowths are seen. The augites have typically a pale greenish central zone of chrome-diopside and a titaniferous zone of purple augite marginally. They invariably show "seive structure" in the inner zone where corrosion has produced numerous fine tubules filled with groundmass material. Locally the titaniferous margin is strongly corroded, numerous closely crowded vermicular cavities having been produced. This is associated with the precipitation of small black grains of, probably, ilmenite and an irregular regrowth of green sodic pyroxene, forming a fringe on the phenocryst.

The augite of the groundmass occurs in grains of varying size, clumps of small granules being associated with considerably larger prisms. They are of the usual purplish colour, and occasionally show marginal corrosion like that of the phenocrysts. They are not scattered uniformly throughout the ground but tend to aggregate in groups and strings forming an open mesh-work. Associated with the augites and of similar size are some octahedra of titanomagnetite.

Conspicuous in the groundmass are prisms of apatite which reach a length of 2.5 mm. and a diameter of .13 mm. They may be seen included in the titaniferous zone of the phenocrysts. In the groundmass, apatite prisms and augite grains are occasionally seen to be mutually anhedral. Elsewhere apatite encloses granular augite. It seems that the apatite crystallised before the last of the titanaugite and continued after it. The outlines of the apatite crystals frequently show marked imperfections of the type usually attributed to magmatic resorption. Such occurrences include some enclosed in augite, but these may be cases of mutual anhedralism. Those imperfect crystals occurring in the groundmass may possibly owe their structure to corrosion. Another type of crystal imperfection is revealed in the development of skeletal crystals. A typical case appears in cross-section as a bundle of parallel prisms, sometimes euhedral, sometimes with irregular outlines. In longitudinal section, these prisms are seen to be united at intervals to form a single skeletal individual bearing elongated inclusions of groundmass material.

Of the felsic minerals the earliest to crystallise were a few tabular oligoclases sometimes showing a marginal growth of albite. They are usually cloudy with iron-stained decomposition products and are partly replaced by zeolites and analcite. As in the normal rock they are poecilitic to the femic minerals and apatite, but may "avoid" these minerals by occurring within the meshes of the open-network structure described above. The same applies to the nepheline which occurs in prisms of various widths and shows replacement to a greater or less extent by the characteristic association of zeolites to be described below. It usually occurs associated with interstitial platy albite which is sometimes simply twinned and easily distinguished from the minor amount of orthoclase occurring elsewhere in the slide by its positive optic sign. The apparent skeletal development of nepheline is again seen. Commonly, also, irregular intergrowths of nepheline and albite occur in which the nepheline portions have no definite shape. Where crystallographic planes are developed however, it is always the nepheline which is euhedral against the albite. Some curious combinations of the two minerals are seen; for instance a core of albite surrounded by a "jacket" of nepheline to form a hexagonal prism. The impression given by such occurrences is that the nepheline has undergone corrosive replacement by albite. Since it is known from physico-chemical investigation that the crystallisation relations of nepheline and albite are of a eutectic rather than a reaction nature it seems that the above structures must be explained by simultaneous crystallisation rather than by resorption.

The nepheline is associated with a peculiar development of pyroxene which occurs in irregular elongated rods or small ragged plates occasionally moulded on the nepheline prisms, more often enclosed in them and projecting a little into the surrounding albite. This pyroxene (Pl.II,4,5) is seen locally to be in continuity with the greenish outgrowths from the augite phenocrysts. These intergrowths serve to indicate the comparatively extensive time range of pyroxene crystallisation. It should be mentioned that wherever pyroxene of this habit occurs it is invariably associated with nepheline or nepheline-albite intergrowth. It is also worthy of remark that a similar pyroxene-nepheline association has been reported by Tilley (1931) from the contaminated dolerite of Scawt Hill, Antrim.

A little clear albite occurs elsewhere in the groundmass either in small well-formed prisms or in irregular patches embedded in the zeolitic base. Groups of small soda-orthoclase laths are seen locally.

The remainder of the groundmass is occupied mainly by zeolites stained in various shades of red-brown. They appear to consist entirely of nepheline decomposition products, some of which have evidently migrated from the pseudomorphs of that mineral and recrystallised in patches less deeply stained. A "high-tide mark" of deeper red staining occurs as a line in the older groundmass immediately surrounding these patches. This recrystallised zeolite is frequently associated with albite which may be seen as a narrow band lining the cavity of redeposition.

In the final stages of its history the groundmass of the rock was replaced locally by cloudy analcite and some chlorite.

The Coarse Phase. (Pl.I,3; Pl.II,4,5)

In this phase augite occurs only as phenocrysts and as the irregular growths associated with nepheline. Olivine phenocrysts are absent. The large augites reach a size of 8 mm. by 2 mm. They have no greenish centres but are titaniferous throughout with a pleochroism from pale brown to deep purple. Lamellar twinning and hour-glass zoning are also seen, and many show the marginal corrosion associated with precipitation of dark oxide and regrowth of green pyroxene that was noticed inthe preceding rock description. Grains of titanomagnetite of about .8 mm. diameter are present, often partly enclosed in the augite phenocrysts. They are typically skeletal in development and are locally replaced by leucoxene and limonite. Brown hornblende occurs in groups of parallel short prisms of about .1 mm.

diameter and is usually completely altered to green chlorite or pale serpentine and limonite. It is possible that some of these prismatic pseudomorphs may represent olivine.

In the groundmass abundant nepheline occurs in prisms of various sizes, of which the largest seen measured 1.7 mm. by .7 mm. Groups of more slender parallel prisms are characteristic so that clusters of hexagonal sections are observed locally in the section. The skeletal habit is somewhat less frequent than in the medium phase, possibly owing to the lower proportion of albite present. As before, skeletal growths of pale purplish or green pyroxene are associated with the nepheline. The latter shows also the characteristic decomposition to zeolites whose staining is responsible for the red colour of the rock. The relative proportions of orthoclase and albite are the reverse of those in the medium phase. Albite occurs as a few vaguely defined plates usually associated with nepheline with which it shows intergrowth structures. Orthoclase occurs in well-formed simply-twinned crystals which tend to a radiate arrangement and vary in size from slender needles to laths over 1 mm. long. The latter may be seen moulded on euhedral nepheline. The entire base of the rock consists of cloudy brown-stained zeolites together with some clear yellowish analcite containing characteristic inclusions of ilmenite and amphibole, the latter in chloritic pseudomorphs. Apatite is present in prisms and needles of various sizes, embedded in all the groundmass constituents and sometimes in the augite phenocrysts. It is just as abundant as in the medium phase, but the prisms are on the whole much slenderer. The absence of biotite from this rock is worthy of note.

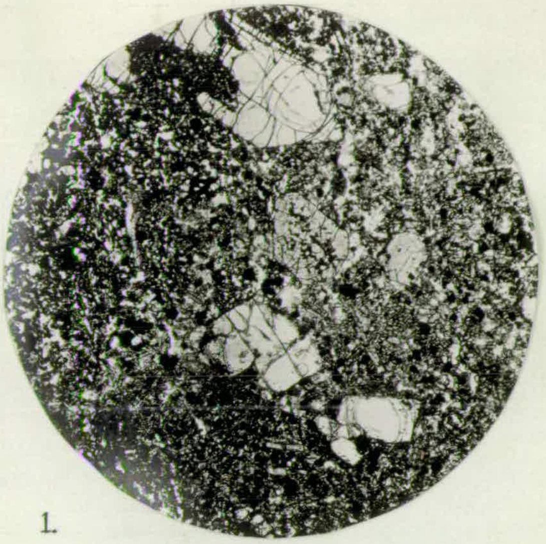
The transition stages from the normal rock to the medium phase show a progressive increase in the numbers of the augite phenocrysts and in the size of these and of the olivines. Augite and magnetite grains become larger and less abundant, the proportion of leucocratic groundmass minerals showing a corresponding increase. The content of apatite shows a marked increase as does that of biotite in the intervening stages. The latter mineral dwindles to a mere remnant in the medium phase. There is a characteristic absence of the clear yellow analcite which, as has been shown, reappears in small quantity in the coarse phase. The platy plagioclase decreases in amount and albite and orthoclase increase. There is of course, an increase in nepheline and its associated zeolites.

Since the coarse phase occurs in schlieren with a fairly abrupt margin, mineralogical transitions between it and the medium phase were not detected. Finer-textured modifications however were observed. Briefly, the mineralogical changes from medium to coarse grades may be summed up as absence of olivine, augite granules, calcic plagioclase and biotite, presence of amphibole, and increased content of orthoclase in relation to the amount of nepheline and albite.

It was previously mentioned that the appearance in hand specimen of the permeation phases suggests that they represent the normal rock with varying content of "vein-matter". The latter has been shown to be of late consolidation and to possess "pegmatitic" tendencies in the sense that certain minerals, notably pyroxene and magnetite in this case, develop a larger grain size. The latter feature and also the presence in the vein of abundant analcite indicate that the original liquor which filled the vein was rich in a "mineralising" fluid containing a considerable proportion of water. Hence an increase in the proportion of this liquor in the magma would be expected to exert a corresponding influence in the direction of "pegmatitic" growth during crystallisation. It has been shown that such was the case, the grain size of the permeation phases increasing in direct proportion to the content of "vein matter". The mineral development in the coarse phase shows, in fact, a strong similarity to that of the veins, differing of course in its larger proportion of augite and magnetite and the possible presence in it of olivine. Since the vein contents were of later crystallisation than the bulk of the femic minerals of the normal rock, there is a possibility that the crystallisation of the entire coarse phase took place at a similar stage.

This might also be expected, being the expression of another "pegmatitic" tendency, namely, that of postponement, in presence of excess fluid, of the precipitation of a mineral to a temperature below that of its normal crystallisation. In this connection, it will be recalled that the coarse phase occurs in schlieren in the medium phase, suggesting that it was still mobile after the augite "network" of the latter had taken shape.

Pl. I.



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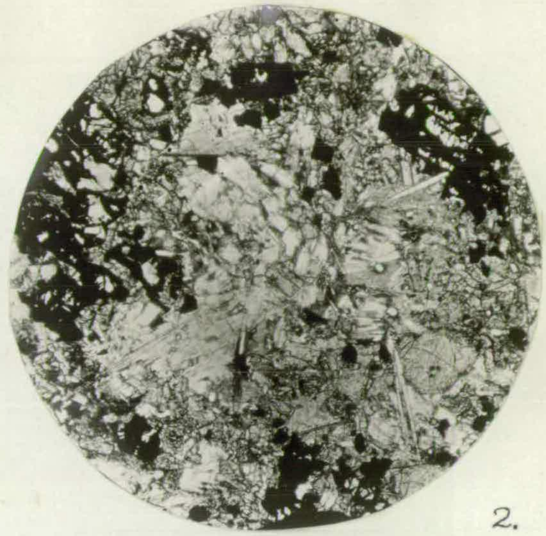

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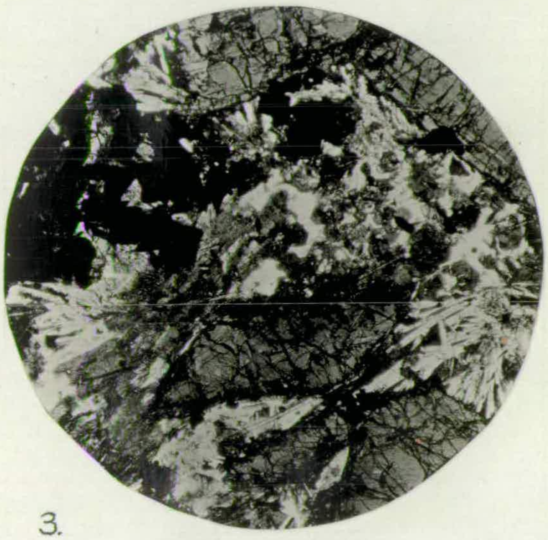

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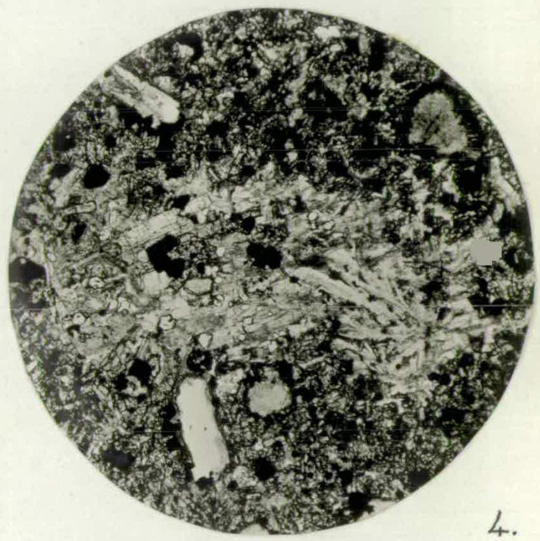

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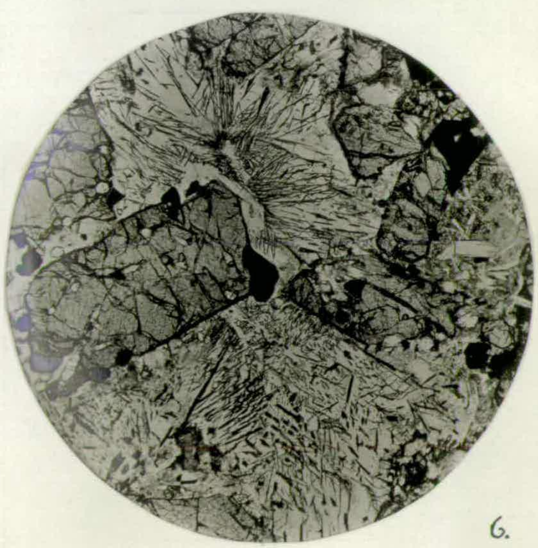


6.

Explanation of Plate I.

1. (Ordinary light x 20). Chesters Quarry, "Normal Rock".

Phenocrysts of fresh olivine and (in centre) of augite. Groundmass granules augite and magnetite with some apatite (light prisms). On left half of field base is yellowish analcite (darker) and on right, poecilitic labradorite, a little nepheline and zeolites.

2. (Ordinary light x 20). Chesters Quarry, "Medium Permeation Phase".

Phenocrysts of altered olivine (dark), and augite (grey). Groundmass augite and magnetite grains, apatite prisms (some skeletal as on lower right). Most of light material is nepheline partly converted to hydronephelite (grey shading) and zeolite x. A few orthoclase laths to right of centre.

3. (Ordinary light x 20). Chesters Quarry, "Extreme Permeation Phase".

Phenocrysts of titanaugite showing hour-glass zoning, and skeletal titanomagnetite. Orthoclase laths in clusters. Rest of groundmass nepheline and albite. Nepheline, partly converted to zeolites (dark grey), shows hexagonal sections on upper right.

4. (Ordinary light x 40). Chesters Quarry, Veinlet in Normal Rock.

Grains of augite and magnetite; on right, radiating orthoclase laths; numerous prisms of apatite (many in cross section); rest of vein-filling is nepheline with some albite.

5. (Ordinary light x 40). Chesters Quarry, junction between Veinlet and Normal Rock (lower right).

Latter contains an altered olivine phenocryst (light) and shows enlarged crystals of augite and magnetite lining vein margin. Vein contains titanaugite and magnetite (upper central) and large plagioclase (upper right). Lower, single chloritised amphibole prism. Groundmass consists of (upper left) clear analcite with slender inclusions of ilmenite, amphibole, and pyroxene. Elsewhere fine matrix of alkali felspar, nepheline, biotite and apatite. In cantre, a "brush" of pyroxene rods associated with albite and altered nepheline. Cloudy patches, as on left, are zeolites, biotite flakes (dark) sometimes giving ocellar structure.

6. (Ordinary light x 40). Chesters Quarry, Veinlet.

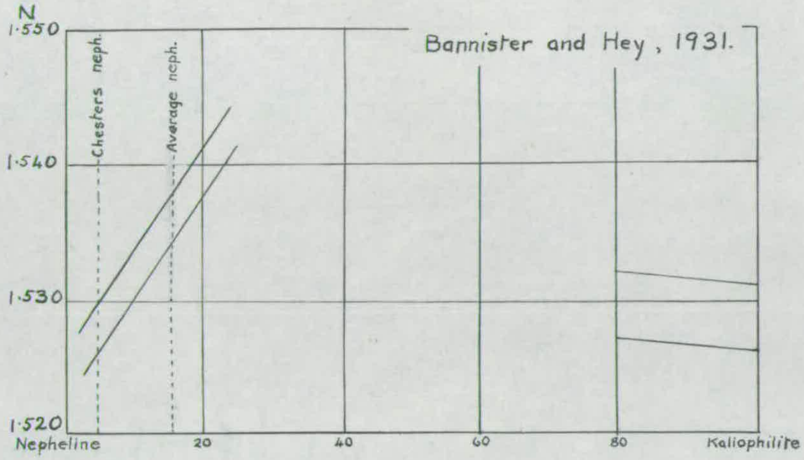
Large crystals of titanaugite enclosing apatite prisms and magnetite grains. Base of clear analcite with inclusions of (upper) ilmenite fibrils and (lower) brown amphibole rods. Upper right, small part of rock groundmass showing enlarged crystals at vein margin.

The Occurrence and Alteration of the Nepheline.(Pl.II)

The presence of nepheline in the Chesters quarry rock was first suggested in 1892 by Hatch and later confirmed by Rosenbusch (1908). In the East Lothian Memoir, Bailey gives mineralogical details of the mineral and points out that it resembles nepheline in most of its properties, namely, hexagonal prismatic form, prismatic basal cleavage, straight extinction, negative prismatic elongation, zeolitic decomposition, gelatinisation with acids and the assumption of stain, and birefringence roughly equal to that of apatite. The refractive indices quoted, 1.526 and 1.522, are, however, considerably lower than those of other recorded nephelines.

Examination by convergent light showed that the mineral was uniaxial negative, and a redetermination of its refractive indices placed the values at 1.530 and 1.526.

Reference was made to the graphs published by Bannister and Hey (1931) showing variation of optical properties in relation to composition of the nepheline-kaliophilite series. They show that the average nepheline has refractive indices of about 1.538 and 1.534, corresponding to a composition containing 16% of the kaliophilite minal.



They also indicate that decrease in potash lowers the refractive indices, and extrapolation shows that the indices of the Chesters rock correspond to a composition containing about 4% kaliophilite. Such a potash content is considerably less than the hitherto recorded minimum of 10%. There is, however, no reason to believe that this mineral is any other than an abnormal variety of nepheline. It has been accepted as such in the Glasgow District Memoir by Bailey, who had previously given it the name nepheline x (East Lothian Memoir).

Calcium occurs to some extent in natural nepheline but the data of Bowen and Greig (1925) indicate that its presence could not account for the low indices of the Chesters mineral.

It is suggested that the latter should be known as "soda-nepheline". Its occurrence among the rocks of the Carbo-Permian Province is widespread, having been

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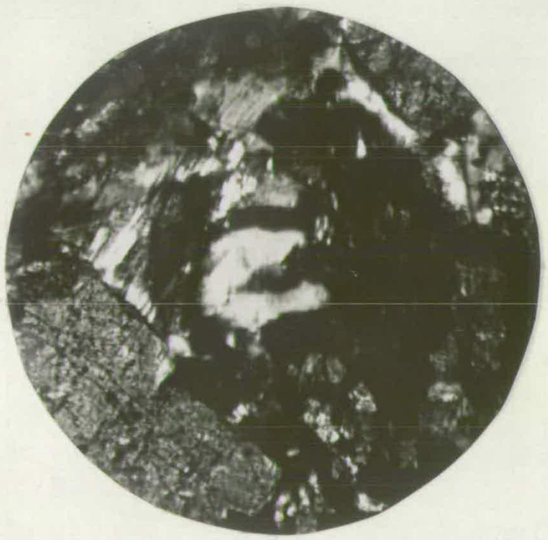

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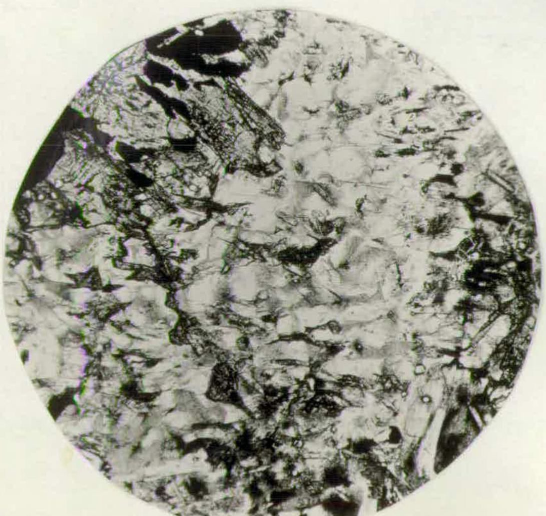


4

5.

Explanation of Plate II.

1. (Crossed nicols x 65). Chesters Quarry, Veinlet in Normal Rock.

Cross-sections of numerous nepheline prisms (in extinction position) embedded in albite. Many show skeletal growth, particularly those in the upper part of the field.

2. (Crossed nicols x 65). Same as 1.

Nepheline in twinned oligoclase which is zoned to albite marginally. Smaller dark spots in felspar are magnetite, and dark areas on right are analcite.

3. (Crossed nicols x 80). Chesters Quarry, Medium Permeation Phase.

Crystal of nepheline in longitudinal extinction position showing intergrowth with albite (light, central and upper). Augite phenocrysts on lower left and upper right. Brilliant flakes in nepheline are zeolite x. This mineral also seen in another more altered crystal of nepheline above augite on left.

4. (Ordinary light x 40). Chesters Quarry, Extreme Permeation Phase.

Upper left, phenocryst of titanaugite associated with skeletal titanomagnetite. Light material is mainly nepheline with a little albite and a few orthoclase laths (lower). Grey shading in nepheline is zeolitic decomposition. The irregular growths of dark mineral in the nepheline are green pyroxene some of which is directly connected to the titanaugite phenocryst.

5. (Ordinary light x 80). Same as 4.

Light mineral represents a cluster of closely grouped nepheline prisms viewed in cross-section. The contain intergrowths of green pyroxene (dark) which is also seen moulded on their hexagonal sections (upper left and lower right).

reported in teschenitic, theralitic, and essexitic rocks in the Glasgow and Ayrshire districts.

An interesting comparison is afforded by the nepheline which occurs in a nepheline-basanite from Partan Craig Vent described by Day and Bailey (1926). A study of the rock revealed that when fresh it must have borne a close resemblance mineralogically to the Chesters rock. Determination of the refractive indices of the nepheline, however, yielded the values 1.538 and 1.534 which correspond to average values for ordinary nepheline.

The soda nepheline shows alteration to at least three distinct zeolitic minerals.

One of these is fully described in the East Lothian Memoir where it is said to present ... "the same appearance as nepheline x but is distinguished by its higher refractive index and birefringence. Its lower index of refraction is about 1.544 while it polarises in straw-yellow tints. Further, it is positive with regard to its length so that between crossed nicols its intricate boundaries against the nepheline x show as thin black lines due to compensation. On treatment with acids its optical properties are destroyed and the residue appears to be clear and isotropic. It is sufficiently distinguished from gibbsite by its straight extinction. Its exact nature is unknown, but it is again found in the west of Scotland associated with nepheline x".

A redetermination of the refractive indices placed the maximum and minimum values at 1.560 and 1.549. Examination with convergent light showed that the mineral was optically positive and was either uniaxial, or biaxial with a very small optic angle. Its polarisation colours reached first order red which is consistent with the determined birefringence of .011. Its is always symmetrically orientated on the nepheline, as indicated above, and commences to replace a crystal at the ends or along crossing cracks spreading in dense flaky aggregates along the prismatic direction. The cross-section of the nepheline prism shows that the alteration product grows in slender lamellae along a series of parallel planes situated at right angles to the base. These planes appear to be in two sets intersecting at an angle of about 30°. The effect thus produced resembles a discontinuous lattice-work or a series of overlapping pointed scales.

As to the nature of the mineral, thomsonite is the first suggestion. The obstacles to its acceptance are the size of its optic angle (47°-75°) and its lower refractive indices. Bannister and Hey (1932) record 1.55 as a maximum value for fully hydrated thomsonite. Now the indices of the mineral under discussion were determined from a microsection which had previously undergone sufficient heating to lower appreciably the refractive indices of any zeolitic product by dehydration. Hence it is probable that, presuming the mineral to be a zeolite, its indices are somewhat higher than the determined values thus making the possibility of its being thomsonite more remote. Ashcroftine, erionite, echellite and jacksonite are all inadmissible on similar grounds although more or less corresponding in other characters. It is probably a zeolite with a high sodic content, akin to thomsonite, and it will be known for the purposes of this paper as zeolite x. It is reported in association with soda-nepheline in the Glasgow (Bailey 1925) and Ayrshire (A.G.MacGregor 1930) districts also. Ordinary nepheline is known to alter on occasion to thomsonite. It is nor unreasonable to suppose that an abnormality in the composition of the original mineral should be expressed as a corresponding abnormality in the alteration product. They occur in intimate connection and both are rare. Does soda-nepheline give rise to a soda-thomsonite?

The most abundant alteration product is a structureless or platy zeolite with typical undulatory extinction. It replaces the nepheline from borders and cracks, no particular direction being adhered to. It may be seen also apparently replacing zeolite x and it is usually stained yellow to reddish brown presumably by ferric hydroxide. It gives a uniaxial positive figure with convergent light, polarises in yellow tints, and shows positive elongation with respect to a single faint eleavage. It assumes no particular optic orientation in the pseudomorph. The refractive indices were determined as 1.500 and 1.490. It thus corresponds in every particular to hydronephelite as described by Clarke (1886), Larsen (1921), Tilley (1931), and others. It differs from natrolite in its uniaxial character, natrolite having an optic angle of about 60°.

Hydronephelite is not of fibrous habit but frequently has this appearance because of abundant inclusions of another fibrous zeolite. The latter is rarely seen alone and then only in recrystallised masses in vesicles. It occurs in the hydronephelite sometimes in scattered granules sometimes in dense growthsof fibres invariably lying parallel to the positive direction and cleavage of the hydronephelite. In the replacement of nepheline the fibres are typically set obliquely to the length of the nepheline prisms. These two zeolites apparently possess the power to migrate together as they are seen in the same intimate association in interstices and in vesicles where the fibrous member often reaches greater relative bulk, occasionally occurring alone. The fibrous mineral was found to have straight or low extinction, positive elongation and a biaxial positive interference figure. Its refractive indices were determined roughly as 1.529 ± .002. These properties seem to correspond to a variety of phillipsite although the occurrence of this potash-calcium zeolite is unexpected, in such quantity at least. The zeolite intergrowth frequently encloses tiny flakes of a highly doubly refracting mineral. These are too small for optic determination but are possibly calcite, cancrinite, or thomsonite.

The hydronephelite-phillipsite association forms by far the larger part of the nepheline decomposition products in the Chesters rock. It invariably shows the reddish-brown staining in some degree. As noted above it may migrate and recrystallise and in this form as well as in pseudomorphs it occupies a large part of the groundmass of the nepheline-rich modifications being responsible for their peculiar colour.

It may be added that zeolite x is never seen outside recognisable pseudomorphs of the nepheline. In other words it shows no tendency to migrate or even recrystallise. Other occurrences of it in East Lothian will be noted in due course.

(b) Stenton.

About a quarter of a mile north of the village of Stenton a pair of plug-like intrusions occur in the Basal Ash of the Volcanic Series. Both have roughly oval sections, the larger and more southerly having a maximum breadth of about 300 yards. The other plug is well exposed in a cliff by the side of the Sauchil Water and shown steep junctions with the ash which is baked and hardened near the contact. In hand specimen the rock is dark, fine-grained and contains numerous microphenocrysts of olivine replaced by a bright red mineral. The appearance is very similar to that of the more decomposed specimens from Chesters Quarry. Streaks and patches of an orange-red substance are also visible, recalling the habit of the veinlets in the latter locality. Lustrous spots about 3 mm. in diameter, corresponding to analcite crystals, are distinctly visible on the freshly broken surface, and are crowded together as in the type rock.

In section, the development of olivine and augite as phenocrysts and of the latter mineral, magnetite, and apatite in the groundmass resembles very closely, in quantity and texture that seen in the normal Chesters rock. Locally, also, a close similarity to the transition stage between the normal and medium phases of Chesters is seen, and, in addition, streaks and patches corresponding to the veins in this sill are observed.

The original aspect of the groundmass base has been largely obscured by its high content of chloritic and ferruginous decomposition products. Much analcite is present sometimes brown and cloudy, sometimes bright orange-red. The latter type may have replaced nepheline as it is seen to occupy well-formed pseudomorphs of this mineral in the vein-like streaks. The cloudy remains of plagioclase crystals occur up to 1 mm. in length and bear ophitic relations to the granular femic minerals. A few small prisms of orthoclase are present and also some albite in small vaguely defined patches, occasionally forming a rim to a small area of colourless analcite.

The vein-material has a bright red appearance in hand specimen where it is seen to occur more often in streaks and "pockets" than in true veins. The colour is due to the orange-red analcite occupying the pseudomorphs after nepheline which bulk largely in this facies. These represent prisms up to 1 mm. long showing idiomorphic outlines and occasionally skeletal intergrowths with interstitial platy albite. Irregular rods of green pyroxene are seen intergrown with the nepheline. Interstitially slender prisms of orthoclase, numerous apatite needles, and a few biotite flakes, occur associated with a base of cloudy analcite.

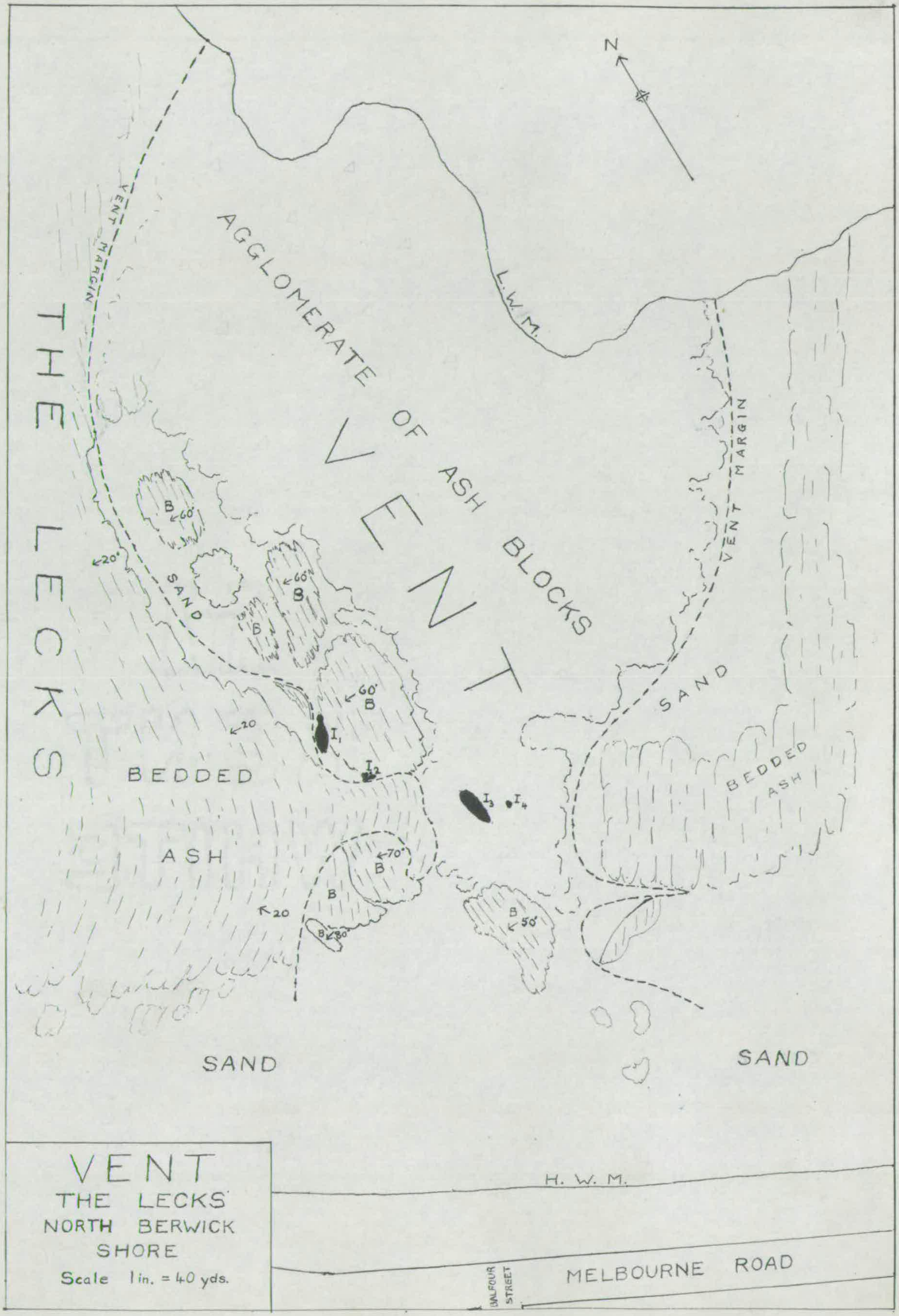
It is apparent that, when fresh, the groundmass and vein-matter must also have borne a close resemblance to their counterparts in the Chesters rock. The Stenton rock is therefore a nepheline-analcite-basanite also.

(c) North Berwick.

On the North Berwick shore, the Basal Ash of the Volcanic Series is well exposed in a broad rocky flat known as The Lecks and lying immediately to the east of the prominent outcrop of the lower lavas which projects seawards from the harbour. The ash dips to the north-west at an angle of about 20% and is of a general red colour containing however several bands of green and grey tints. It is more or less calcareous throughout and intercalations of ashy marl are frequent, one of these containing plant remains. As the outcrops are traversed in an easterly direction darker-coloured and poorly stratified beds of lapilli become more frequent. At one horizon a band of agglomerate about 2 yards thick was observed. As the contents of this band are of peculiar interest it will be described more fully in a later section (p.120).

About a furlong south-east of the harbour promontory the margin of a vent cuts across the stratified ash (see map Pl.III). The vent contains a coarse agglomerate composed of blocks of ash similar to that occurring throughout The Lecks. The matrix is a fine red unstratified ash. Many of the blocks are of considerable size, the larger ones (B) occurring grouped

Pl. III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VENT MARGIN
AGGLOMERATE OF ASH BLOCKS
L.W.M.
THE LECKS
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70°
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20
B
80
B
50°
SAND
SAND
VENT
THE LECKS
NORTH BERWICK
SHORE
Scale 1 in. = 40 yds.
H. W. M.
BALFOUR STREET
MELBOURNE ROAD

along the western margin where most of them lie with bedding planes steeply tilted and striking approximately north and south. These blocks probably represent the foundering of the vent edge. Within the vent the blocks are generally about 1 to 3 ft. in diameter although a few have a width of several yards. These frequently show signs of disturbance in the form of small local contortions of the beds, numerous small faults with a slip of an inch or two, and, occasional brecciation of a more calcareous band. The junctions between two larger blocks or between a block and the vent edge are frequently seen to be of an intricately sutured nature as if the ash had been, at the time of disturbance, in a poorly compacted condition. Admittedly, ashy sediments owing to their "greasy" matrix may yield plastically under compression, but it is highly improbable that such could produce interlocking block-edges in consolidated ash without leaving abundant other traces of its action. The above evidence suggests that the ash was but little older than the explosions that disturbed it, being as yet only partly consolidated. The vent activity has also produced disturbance in the surrounding strata in the form of a gentle folding along east-west axes on the western side.

The vent contains four small plug-like intrusions (I_1, I_2) which have baked and marmorised the surrounding ash to a small extent at their contacts. The two largest (I_1 and I_3) have elongate oval outlines, I_1 lies on the vent margin and both it and I_3 appear as small hummocks rising a little above the general level of the rocks, without however, forming conspicuous features. I_2 is more irregular in outline, resembling a group of blocks embedded in the ash. It also occurs at the vent margin and may be completely obscured by sand in times of storm. The smallest, I_4, appears as a prominent rounded knoll about a yard in diameter arising from the ash close to I_3.

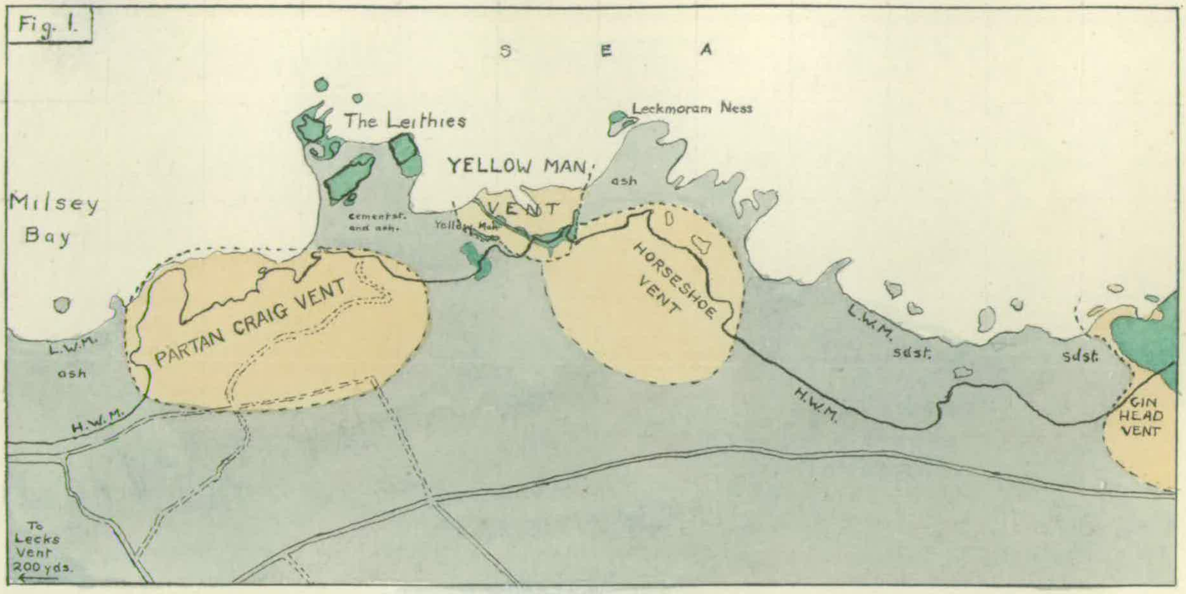
The plugs all consist of the same rock which in hand specimen has a dark, fine-textured appearance and shows lustrous spots 3 mm. in diameter, revealing the presence of pseudoporphyritic analcite. Porphyritic olivine pseudomorphed by a dark brown flaky substance, occurs in a few crystals up to 5 mm. long and in numerous smaller ones about .5 mm. long. Vesicles filled with calcite and some chlorite are present in varying numbers. Locally, where they are abundant, they are associated with advanced calcification and chloritisation of the rock which here assumes a light purplish or brownish tint contrasting with the dark colour of the olivine phenocrysts.

The freshest specimen, from the centre of I_3, strongly resembles in section the fine-grained facies of the normal Chesters rock. The only porphyritic mineral however is olivine. Plagioclase occurs in laths of labradorite and some oligoclase. These reach a length of 1 mm. and enclose poecilitically the augite and magnetite grains which occur in abundance in the groundmass. No nepheline or zeolites were detected but any representatives of these may have been replaced by the pale chlorite which occurs, frequently in considerable amount, in the interstices. About half of the groundmass base is occupied by clear yellowish analcite which contains densely crowded inclusions similar to those in the Chesters rock. Locally the analcite shows extensive replacement by the pale chlorite, and the appearance of the lustrous spots on the rock surface shows that it crystallises in the same manner as in the type rock.

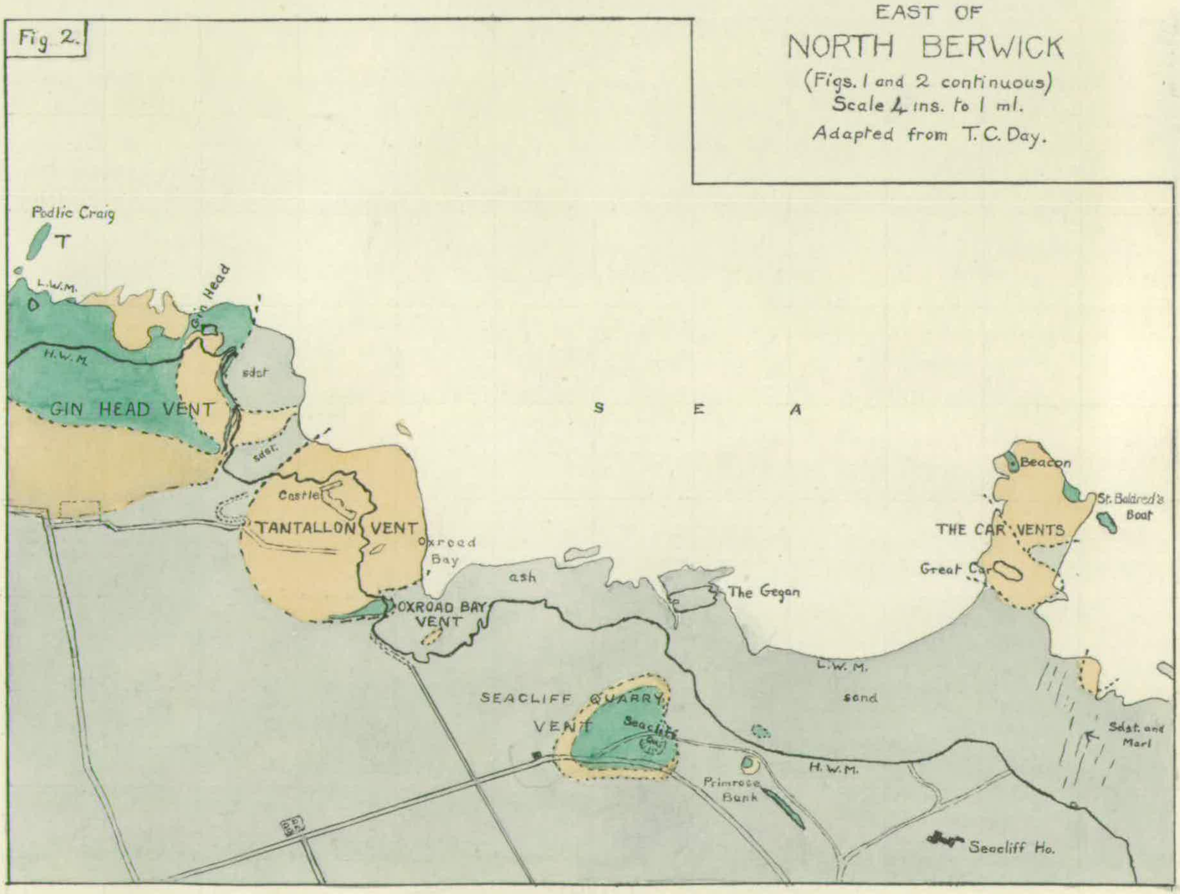
On the eastern side of the harbour promontory at North Berwick, a small plug is seen to cut the red Basal Ash at a point about 80 yards south-west of Swiney Craigs. The plug is only slightly larger than the largest (I_3) in The Lecks Vent and the rock is exactly similar in hand specimen and microsection to that of the Vent plugs.

(d) The Leithies.

About 1¾ miles east of North Berwick a group of eight islets known as the Leithies occurs between tidal limits (see map pl. IV). They have been interpreted by T.C. Day as the remains of a small laccolith and are associated with the Basal Ash which is here green and



COAST
EAST OF
NORTH BERWICK
(Figs. 1 and 2 continuous)
Scale 4 ins. to 1 ml.
Adapted from T. C. Day.



Basanite; also teschenite (T). — Agglomerate in Vents. — Cementstone Series.

dolomitic. Day (1925) described the rock of which they consist as a monchiquite, and published an analysis which is quoted on p.

The rock is dark and fine-grained and shows the familiar lustrous spots. In section it bears a very close resemblance to the normal Chesters rock. The poecilitic labradorite laths have more sodic borders. Nepheline occurs interstitially in small amount and shows partial replacement by analcite and pale chlorite. The zeolites characteristic of the Chesters rock are absent but otherwise the distribution and habits of the minerals are essentially similar to their counterparts in the type locality.

It is interesting to observe that in the finer-grained marginal phases of the Leithies rock, the augite content appears to increase and the relative size of the labradorite laths decreases so that they appear as small more or less discrete crystals. The marginal phase of the Chesters sill is not exposed but an examination of that of the Stenton intrusions revealed a similar appearance.

(e) Partan Craig.

A nepheline-basanite occurring as bombs in the Partan Craig Vent (Pl.IV) was described by Day and Bailey

(1932). An examination of Day's slides shows that this rock resembles in many respects some of the intermediate "permeation" phases of the Chesters sill. The probability of its being akin to the Chesters type is strengthened by the occurrence in the same vent of blocks of comparatively fresh rocks which in section are practically indistinguishable from the normal Chesters rock and some of the lower permeation grades. The nepheline is however more usually euhedral to the albite, skeletal intergrowths being infrequent (compare the well-formed nepheline in the above basanite). The felspar consists of oligoclase with albite borders and also some interstitial albite and orthoclase.

Yellow Man.

Blocks similar to the ones just described occur in the agglomerate of the Yellow Man Vent (Pl. IV) where they are easily recognised by their spotted appearance, the spots being crowded together as in the Chesters rock. Some remarkably fresh examples occur, much of the olivine and nepheline being unaltered. Biotite is present in slightly greater quantity than in Chesters.

Gin Head.

The Gin Head Vent also contains blocks of Chesters type. In these the nepheline is represented by pseudomorphs, occasionally euhedral, of reddish-stained cloudy analcite. The relations of these blocks to the basanitic intrusion at Gin Head will be discussed in a later section. (p.105).

The close proximity of the occurrences of Chesters type at The Leithies, Partan Craig and The Yellow Man suggest that they are if not of identical origin, at least of similar age. The grain size of the vent blocks indicatesthat they once formed part of either a fairly large intrusion situated at little depth or else a less extensive but deeper-seated injection such as for example a feeder of the Leithies laccolite. These vents and that at Gin Head as mentioned before, contain no blocks of later age than Calciferous Sandstone suggesting that they ceased activity in the later part of this period. If this be so a Calciferous Sandstone age can be assigned to a few at least of the occurrences of Chesters type. The question as to whether the Leithies, Chesters and Stenton intrusions are of the same period must remain speculative. The Lecks plugs, as will be seen (p.123) are probably of later date than Upper Calciferous Sandstone times,

Chesters Type: Summary.

The characters which distinguish this rock type include the following:-

(a) A high (lamprophyric) content of augite, mainly in groundmass granules.

(b) Plagioclase occurring in elongated plates having poecilitic relations to the rest of the groundmass minerals.

(c) Abundant analcite usually forming more than half of the groundmass base and occurring in closely crowded poecilitic individuals.

(d) The presence of apatite as an important accessory, occurring in prisms up to ½ mm. long and having ophitic relations to the augite and magnetite granules, and also appearing as fine needles in the analcite.

(e) The presence of nepheline in small amount in most of the occurrences. Those in which it is absent have a decomposed groundmass which possibly once contained the mineral.

As was previously noted, various names have been given to the Chesters (normal) rock; these include limburgite, monchiquite, and nepheline-basalt. The name limburgite was evidently given under the impression that the base was glassy. Monchiquite, strictly speaking, designates a rock without felspar and having a base composed entirely of analcite. Locally, in the Chesters rock, calcic plagioclase appears to be absent. This appearance, as has already been pointed out, is probably due to the replacement of the felspar by late cloudy analcite. In several instances remnants of felspar were observed. In any case, such specimens usually contain a little albite and possibly also some orthoclase. In the rock described as the Chesters normal rock and taken as the type of this division, plagioclase is always present in sufficient quantity to exclude the rock from the monchiquite category. Again, the name nepheline-basalt indicates a felspar-free rock with essential nepheline. It cannot therefore be applied in this case as, in addition to the presence of felspar, the nepheline occurs in minor amount only. The presence of both plagioclase and abundant felspathoid (analcite with some nepheline) gives the rock a basanitic character, but in view of the preponderance of augite over felspar and felspathoid it must be assigned to the melabasanites (Johannsen 1938). It is proposed, therefore, to call the group of rocks described in the preceding pages melabasanites of the Chesters type.

A discussion of the chemical analyses of several members if this division will be found on p. 110.

B. ANALCITE-BASANITES AND OTHER ANALCITE-MELABASANITES

The basanitic rocks of this diversion form, structurally as well as mineralogically, a more or less continuous series. All are analcite-rich, the chief variation occurring in the augite-felspar ratio. The more augitic members of the series are true melabasanites, having a pyroxene content approximately equal to that of the Chesters type from which they differ however in certain structural features. Apart from a single example which is exceptionally rich in felspar and also a few in which the base is glassy, the rocks of this diversion are fairly evenly distributed over a range at the most felspathic end of which only a slight predominance of light over dark minerals exists.

The series can therefore be divided into four groups. The first consists of the single more highly felspathic instance mentioned above. The second comprises the rocks at the less femic end of the range just referred to. These may be called true basanites (as distinct from melabasanites) as the femic minerals show at the most a slight excess over the felsic. In the third group femic minerals especially augite are distinctly predominant, the members being therefore melabasanites. A fourth group includes the glassy rocks.

GROUP I.

This group is characterised by a considerable excess of felspar over augite, these minerals occurring in approximately the same relative proportions as in a basalt of the Dalmeny type.

Seacliff Quarry

The only observed occurrence of this group consists of a large intrusive mass, a furlong in diameter, which is well exposed in Seacliff Quarry (Pl.IV). It was interpreted by Day (1932) as a plug situated in a vent whose diameted does not exceed that of the intrusion by many yards. The irregular jointing of the mass was described and photographed by the same author.

In hand specimen the rock is of dark grey colour and fine texture, and shows numerous micrephenocrysts of olivine and augite. Sporadic augites up to 8 mm. in diameter are also visible. The analcite crystals are exceptionally well-developed and appear as rounded areas 3 to 4 mm. in diameter, having a high lustre, and providing one of the best examples of the pseudoporphyritic structure in East Lothian.

In microsection the augite phenocrysts are seen to exceed in number those of olivine. Both occur in a variety of sizes, the olivine from .2mm. to 1mm. and the augite from .1mm. to 1.3mm. The former are completely altered to green serpentine and the latter, which are pale purplish with an occasional greenish core, show sieve-structure to a marked degree. Occasional laths of labradorite 1 mm. long also occur among the phenocrysts.

The augite and magnetite of the groundmass occur in minute granules. Magnetite is also present in fewer and larger octahedral grains. The felspar consists of labradorite in laths varying in size from microlites to cyrstals .5 mm. in length.

The analcite is clear and yellowish and appears in rounded patches without definite crystal outlines and having the usual poecilitic relations to the other minerals. It also encloses numerous fine apatite needles. Viewed under crossed nicols the analcite patches are seen to be distinctly less felspathic than the rest of the groundmass. Moreover the felspar which they enclose is obviously corroded, the smaller laths having locally disappeared. The liquor which deposited the analcite evidently possessed the power to dissolve the felspar. Evidence suggestive of this action is frequently encountered among the basanites, and other instances will be noted in due course.

GROUP II.

In this group the femic : felsic ratio varies in value from a little less to a little greater than unity.

Occurrences:-

(a) Kidlaw, in the south-west part of the county: a plug in a vent piercing the Upper Old Red Sandstone.

(b) The Knockenhair, Dunbar; a plug in a vent piercing Cementstone sediments.

(c) The Black Rocks, on the shore $\frac{3}{4}$ ml. north of Gullane; a sill intruded into Calciferous Sandstone sediments overlying the Volcanic Series.

(d) West Fenton, $1\frac{1}{2}$ mls. south-east of Gullane; a small sill intruded into Calciferous Sandstone sediments overlying the Volcanic Series.

(e) Swiney Craigs, North Berwick; an intrusion of doubtful form, cutting rocks of Cementstone age.

(f) Yellow Man Vent (Pl.IV); a dyke cutting the knoll known as The Yellow Man.

(g) Garvald, near Chesters; a plug-like intrusion in the Upper Old Red Sandstone.

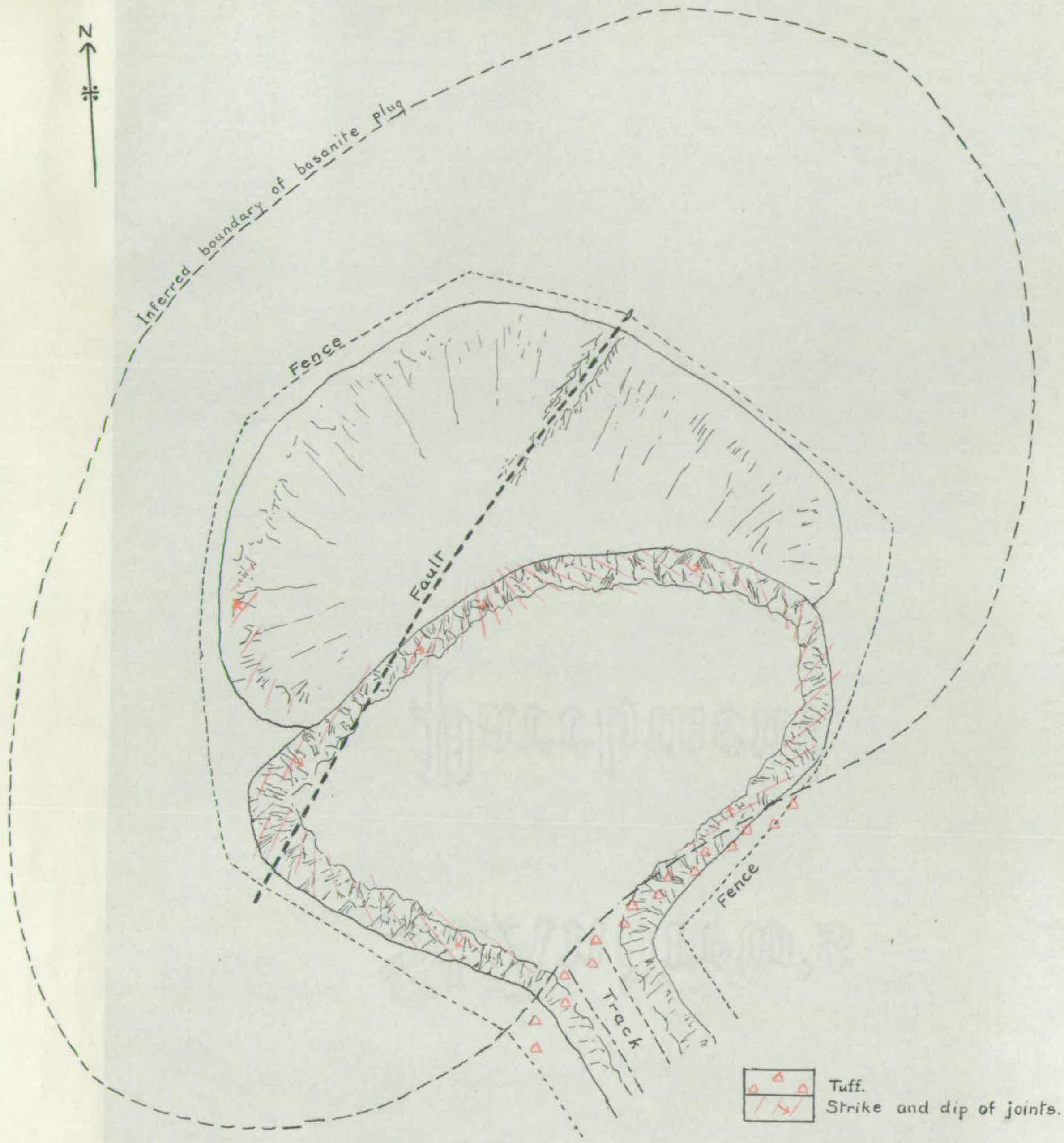
(h) Fidra, and island 2 mls. W.N.W. of North Berwick; presumably a stock. Relations to sediments unknown but probably cutting Upper Calciferous Sandstone strata.

(a) KIDLAW INTRUSION.

The intrusion of analcite-basanite occurring in the Upper Old Red Sandstone at Kidlaw gives rise topo-:graphically to a low hill and has been well exposed in a circular quarry about 80 yards in diameter (see sketch-map). In the Survey Memoir it is considered to be a sill but re-examination by Simpson (1932) revealed an outcrop of tuff with steep junction to the basanite indicating a plug-like structure for the latter. Comparisons of textures in microsections cut from different points in the quarry confirm this and also suggest that the boundary of the plug does not extend far beyond that of the quarry but corresponds roughly to the circumference of the small hill. The disposition of the major joints agrees with this conclusion. Platy jointing is developed parallel to the steep junction with the tuff. Elsewhere in the quarry the somewhat irregular tangential trend of the joints when compared with the regular columnar structures developed in small sills like those at West Fenton, Black Rocks and Eyebroughy Scar, forms a strong indication that the habit of the rock-body is plug-like rather than sill-like. A fault cut across the quarry in a direction parallel to the Southern Upland Fault which occurs about 300 yards to the south-east. The fault line is occupied by a breccia consisting of fragments of granite, greywacké, shale, and the basanite, cemented by a brown siliceous matrix containing numerous grains of quartz and felspar. The occurrence of such a representative suite of Older Palaeozoic rock fragments seems at first sight paradoxical until it is recalled that rocks of this age occur about 300 yards to the south and at one time doubtless actually overtopped the Kidlaw area, as the Southern Upland dislocation is a reversed fault.

The petrology of the Kidlaw rock has been discussed in detail by Bailey in the East Lothian Memoir. To summarise briefly, the rock is dark, fine-grained and shows well-developed spots, light-coloured on the weathered surface and lustrous on the fresh face, corresponding to analcite crystals. The section shows a few scattered microphenocrysts of olivine and augite similar in appearance to those occurring elsewhere among the basanites. The groundmass is peculiar in that it contains small fresh olivine crystals. The usual augite and magnetite grains are present and abundant small laths of labradorite, occasionally zoned to albite and sometimes mantled by orthoclase. A little interstitial nepheline is tentatively reported, and also plentiful biotite flakes and small apatite needles. The analcite occurs in the familiar poecilitic patches, the total amount being somewhat less than that of felspar.

A study of the rock confirmed the presence of a minor amount of nepheline. It occurs as small hexagonal



PLAN OF

KIDLAW QUARRY

Scale 1in. = 20yds.

prisms whose shape is usually modified on account of its interstitial relations to the plagioclase laths. It gives the normal uniaxial negative interference figure and usually presents a distinctive appearance due to its partial replacement by clear analcite and chlorite along borders and cleavages. It is seen in best development in fine vein-like felspathic streaks and patches recalling those occurring in the Black Rocks and doubtless having a similar origin.

The crystals of analcite appear in section as rounded yellowish areas, deeper in colour and slightly cloudy towards the margin and varying in diameter from ½ m.m. in the finer grades to about 3 m.m. in the coarser. Occasional fusion of two or more gives the appearance of larger individuals. The crystals have generally rounded outlines, but the actual boundaries are irregular, no crystal form being observed. They have the same refractive index 1.490 as was observed in the primary analcite of Chesters.

The analcite crystals have poecilitic relations to the groundmass minerals, olivine, augite, magnetite and labradorite. The laths of the latter mineral enclosed in the analcite are slenderer than those occurring elsewhere due to the absence of sodic zones. They also show signs of corrosion indicating that the sodic felspar at least has been replaced by analcite. Orthoclase and biotite are also absent from the analcite patches. The latter frequently enclose olivine phenocrysts and the augite spherulites so common in the rock as if the analcite had formed on these as nuclei. Areas of analcite inside the crystals, free from or poor in inclusions correspond to the felspathic streaks in the groundmass and like them are probably due to tension fissuring.

The development of the analcite crystals in the fine-grained marginal zone of the Kidlaw Plug is of special interest. The rock here is very fresh, the olivines in the groundmass being for the most part unaltered. The analcite crystals range up to ½ m.m. in diameter. They are frequently seen to have as a core a rounded or octagonally shaped clear area containing a central group of minute inclusions and resembling closely the habit of a small leucite crystal, (Pl.IX,4). There "leucitohedrons" vary in size, the larger ones appearing as a circular area characterised by a dense concentration of magnetite dust and typically surrounded by a narrow clear band. As they become larger in specimens further from the margin, their leucite-like character gradually disappears. The concentration of black dust becomes less obvious and the clear band is soon no longer evident. The above structures form the nuclei on which the analcite crystals have crystallised. They are formed of the same material as the rest of the crystal but the fact that definite octagonal outlines have been discerned points to the previous existence of another mineral which has been pseudomorphid by the analcite. The possibility of this mineral having been leucite will be discussed later in connection with the occurrences of leucite elsewhere among the basanites of East Lothian.

AUGITE SPHERULITES, (Pl.IV)

A prominent characteristic of the fine-grained basaltic rocks of the Scottish Carboniferous Province is the occurrence of small augite prisms in radiating clusters frequently showing a centre of alkali felspar and analcite and occasionally a core of quartz. Such structures are of familiar occurrence among the Continental Tertiary Basalts and were given the names "augitaugen" by Rosenbusch (1908) and "oeillets d'augite" by Lacroix (1893). Since the word "eye" is associated with other geological structures it is proposed to refer to them as "chondroids" from their superficial resemblance to the chondrules of meteorites.

These chondroids are particularly abundant in the Kidlaw rock where they are considerably more numerous than the phenocrysts, and were observed in varying amount in all specimens taken from the quarry. The average diameter is about .2 m.m. but diameters up to 1 m.m. are not infrequent. Generally they have a circular or ovoid shape in section but may be elongated or distinctly angular. Locally they tend to occur in groups and strings.

The following is a general account of their structure and mineralogy.

A central zone contains orthoclase and possibly some albite, associated with varying amounts of analcite, calcite, and chlorite, the last three probably replacing glass. This is followed by a zone of augite in inwardly converging prisms. Generally the bulk of the augite is a pale diopside but it may be more or less titaniferous especially on the outer margin of the zone where, also, the augite prisms are more closely compacted and smaller. Towards the interior of this zone they tend to become more sodic as is shown by the appearance of brighter green colouration. Here also they are associated with small flakes of a brown sodic amphibole and occasionally with a deep brown mineral resembling amphibole. It occurs in small ragged prisms with longitudinal cleavage and an observed maximum extinction angle of 39°. The cleavage in cross section was not observed. The mineral is pleochroic in very deep red-brown tones. Its extinction angle is too large for barkevikite or common hornblende. It was therefore concluded to be either a kataphoritic hornblende or cossyrite. Between the augite and the main rock there is a narrow zone consisting of much platy albite, a little orthoclase, flakes of brown biotite and occasionally a little well developed nepheline. A few augite and magnetite granules are also present. Frequently the whole chondroid is enveloped in an analcite crystal which has formed on it as nucleus. Locally, however, the material of the outer albitic zone has breached the analcite sheath and, mingling with the groundmass, has given rise to extensive local development of biotite and platy albite. Much of the biotite developed in the Kidlaw rock occurs concentrated in streaks which are rich in alkali felspar and many of these streaks are seen to be directly connected with chondroids in the manner described above. Possibly the rock would have precipitated some biotite in the normal course of events in absence of the chondroids but the above evidence suggests that the latter exerted some control over its appearance. It is proposed to discuss the nature of this control in the sequel.

In the smaller chondroids the augite extends to the centre and no surrounding felspathic zone is visible. All gradations exist between these and the larger type with distinct zones as described above. Also, the stages from the latter to somewhat larger individuals with a residual core of quartz can be traced.

A typical example of this type has a centre of quartz, about $\frac{1}{8}$ in. diameter, traversed by an irregular network of cracks, along which glass had been produced, associated with grains of brown sodic amphibole and green sodic pyroxene. The glass is mainly replaced by analcite and chlorite. The zone immediately surrounding the quartz core consists of the familiar inwardly radiating diopside prisms, more sodic on the inner margin of the zone where they are associated with brown amphibole and possibly also cossyrite. The matrix at this part consists of glass and orthoclase laths. On the outer margin of the augite zone the pyroxene is more granular and shows the purplish titaniferous character noticed before. The alkali-felspar zone and analcite sheath correspond exactly to those previously described. Also the abundant precipitation of biotite at gaps in this sheath is noticeable, the biotite and associated albite felspar occurring in correspondingly larger crystals. The sheath of analcite surrounding these larger chondroids is obviously composed of a closely compacted mass on analcite crystals and may reach a thickness of ½ c.m. Thus the various reaction zones surrounding the quartz xenocryst correspond in such minute detail with the structure of the typical chondroid in which no quartz is apparent that there can be no doubt that they are of similar origin.

Other evidence in support of this view may be adduced from various sources. Before reviewing this however, possible alternative suggestions as regards the origin of chondroids will be considered.

It may be suggested that those consisting of augite only and showing no central zone may represent points of spontaneous crystallisation in a magma super-cooled in regard to augite. If such were the case they would show regular spherulitic structure with obvious indication that growth had taken place from within outwards whereas the opposite is evinced by the chondroids. Again, the latter may be postulated as reaction growths on a previously crystallised mineral. No trace of any such mineral has been observed either on Scotland or on the Continent, even in chilled phases of the rocks, whereas grains of quartz are reported in many localities embedded in chilled basaltic rock and showing only incipient reaction with the magma.

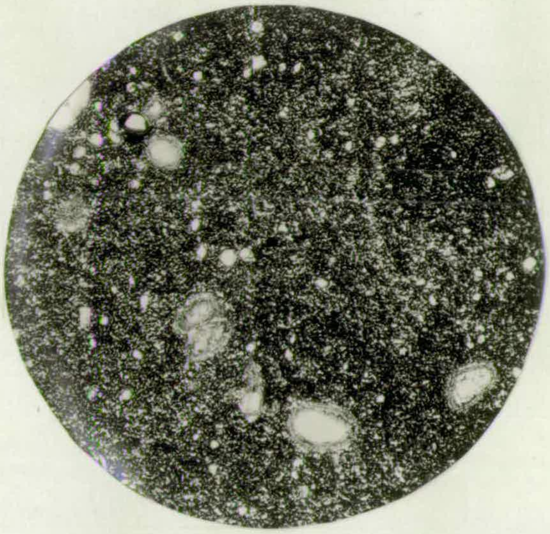
Such occurrences, it may be added, are common in the chilled margin of the Kidlaw plug.

It may also be suggested that these structures are due to the presence in the magma of immiscible fluid globules which later reacted with the magma to produce the augite and associated minerals. Such globules would have to be highly siliceous and considerably alkaline, granitic in fact. It is difficult to imagine how they could have kept their shape in view of the evident flowage to which the parallelism of the labradorite crystals frequently testifies. Moreover such a conception is at variance with experimental results on the miscibility of basaltic and granitic liquids. The originator of a chondroid must then be a solid siliceous body, associated with or having the power to assimilate from the magma, a certain amount of alkali. These conditions are satisfied by a xenocryst of quartz.

In the Kidlaw plug the source of the quartz grains might well be the Old Red Sandstone formations through which the vent containing the plug has been drilled. It may seem at first sight improbable if not impossible that quartz grains should have become so disseminated throughout a rock so that at least one or two should appear in every section cut. Flett (1902) however, describes from East Fife several vent intrusions through which quartz xenoliths and grains have been disseminated in the above manner and only incipiently altered due to the rapid chilling of the intrusions in question. In one case he suggests an unconsolidated arenaceous rock as the source of the abundant quartz grains. It will be recalled also that the chondroids in Kidlaw tend to occur in groups and strings.

Reynolds (1936) describes the digestion of quartzite xenoliths by a hornblendite magma. The xenoliths effected a selective concentration of alumina, potash, and soda, that of potash for instance exceeding that of soda. Bailey (1916) described the concentration of alkali by a quartzite xenolith in a porphyrite in Glencoe, and Campbell and Stenhouse (1934) describe a similar concentration by quartzite xenoliths in the Braefoot Outer (teschenitic) Sill. Holmes (1936) analysed the glass surrounding quartzite xenoliths in murambite and katungite and demonstrated there also a concentration of alumina and alkalis.

It appears then that a siliceous inclusion in a basaltic rock commences early in the history of the rock's crystallisation to assimilate selectively alumina and alkalis. When the inclusions are numerous such segregation of potash and soda must impoverish the magma considerably in these constituents especially potash. This must to a large extent restrict the entry of alkalinominals into the molecules of early formed minerals such as augite and labradorite. It has been shown how these alkalis are in part restored to the rock after the crystallisation of the early femic minerals, the labradorite, and the analcite has been completed. They crystallise as albite with some orthoclase, and the excess of potash, in conjunction with



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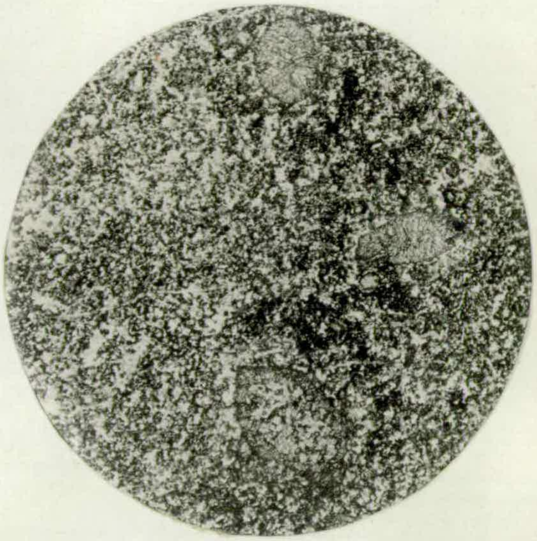

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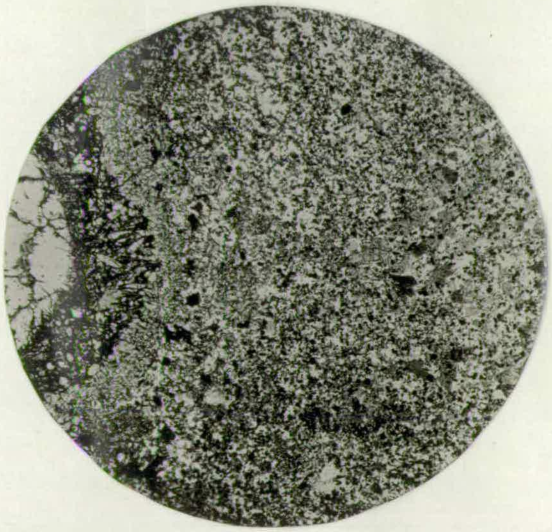

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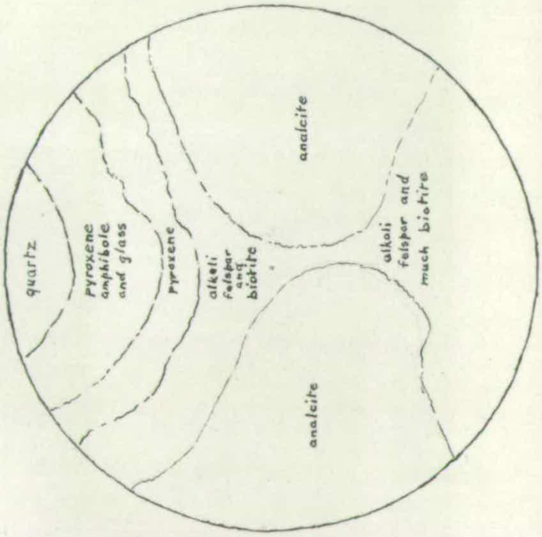

quartz
pyroxene amphibole and glass
pyroxene
alkali felspar and biotite
analcite
alkali felspar and much biotite
analcite

4.

Explanation of Plate VI.

1. (Ordinary light x 20). Kidlaw intrusion, marginal.

Inclusions of quartz grains showing conversion, by reaction, to chondroids. Grains near centre completely converted. The largest grain (lower) shows residual core of quartz. The small bright spots throughout the field are the small fresh olivines of the groundmass. A single microphenocryst of olivine occurs on the upper left border.

2. (Ordinary light x 20). Kidlaw intrusion.

Shows three chondroids. Each has a zone of pyroxene needles projecting into a central zone of alkali felspar, and is surrounded by a narrow felspathic zone containing biotite flakes (dark and grey, best seen in central example).

3 and 4. (Ordinary light x 15). Kidlaw intrusion.

Reaction zones surrounding a quartz xenolith. Illustrating the process of biotite production in the rock. Explanation in 4. The analcite encloses poecilitically the augite and magnetite granules of the groundmass. Augite granules are also present in the "alkali felspar and biotite" zone.

the late 'chloritic' iron of the residual liquor of the rock, produces abundant biotite. Thus an abnormal development of biotite may be the result of the inclusion and reaction of quartzose xenoliths. This is supported by evidence from the Binny Craig, West Lothian. Here Lunn (1932) describes the inclusion of abundant quartz grains in a basalt sill and the extensive development of chondroids from them. He makes the significant statement that "thin brown scales of biotite are common in sections with much included foreign matter (quartz grains)". Elsewhere in East Lothian suggestive evidence is available. The Knockenhair plug consists of a rock closely similar to the Kidlaw basanite, containing abundant chondroids and also plentiful biotite flakes. The sill at West Fenton, however, though closely resembling the Kidlaw type mineralogically except for the absence of both biotite and the obvious excess of late alkalis, contains very few chondroids. It is not suggested here that the appearance of biotite is invariably controlled by such circumstances as those outlined above. Rocks like the Chesters sill where chondroids are present in very small amount contain a considerable development of biotite. The suggestion is merely that by localised temporary differentiation on a small scale, a certain amount of liquid is produced sufficiently alkaline to precipitate biotite. To take a concrete example, if the West Fenton sill had contained abundant xenocrysts of quartz, biotite would have appeared throughout the rock in similar amount as that seen at Kidlaw.

Another result of the late restoration of segregated alkalis to the rock is that the latter appears to be slightly richer in alkalis than is actually the case. This effect is produced by the higher proportion of visible alkali felspar. The analysis however, of the Kidlaw plug, for example, shows a comparatively low alkali content and potash-soda ratio, when allowance is made for the considerable quantity of analcite.

Although the inclusion of quartz in the Kidlaw rock has been stressed, the actual bulk of the quartz is comparatively small and has probably served to raise the silica percentage about 1%. The rock analysis it may be added yields on computation 7.4% of normative nepheline.

It would serve no useful purpose to describe in detail the other occurrences of chondroids observed in the basaltic laves and intrusions of the Lothians and the Kinghorn district of Fife (Allan 1924). Suffice to say that they form supporting evidence to the theory of formation described above, a theory, by the way, which was probably first proposed by Lacroix in 1893 in his classic "Enclaves" where he describes in detail the production of "eyelets of augite" from quartz xenocrysts in basaltic magmas.

(b) The Knockenhair.

This intrusion outcrops as a small crag on the summit of a prominent hillock on the outskirts of Dunbar. It forms a plug in a large vent ½ mile in diameter piercing lower Cementstone sediments.

In the Memoir it is mentioned as being "of the Kidlaw type". Its resemblance to the Kidlaw rock is very close both in hand specimen and in microsection. In particular the occurrence of olivine as scattered microphenocrysts and also as numerous small grains in the groundmass; the presence of a number of small chondroids with associated development of biotite flakes; and the pseudoporphyritic habit of the analcite are noticeable in this connection.

(c) THE BLACK ROCKS, GULLANE.

The sill of analcite-basanite which is known as The Black Rocks is exposed on the shore about $\frac{3}{4}$ mile north of Gullane. It outcrops within tidal limits for a distance alongshore of about $\frac{1}{4}$ of a mile.

The actual contacts with the sediments, except for a thin offshoot on the northern edge of the sill are obscured, by dune-sand to landward and by beach deposits and water to seaward.

The sill shows well developed columnar jointing and dips gently to landward. Microscopic study of specimens from different parts of the exposure indicate that the sill has a lenticular form truncated somewhat abruptly on the north side, possibly by an obscured fault. Fineness of grain on the seaward margin suggests that the base of the sill is roughly coincident with low water mark. A similar criterion places the top of the sill as not far above high water mark and likewise parallel to it. These conclusions are supported by other evidence in the form of irregular areas of white trap occurring at different points along the outcrop and increasing in extent towards the south end. This trap rock consists of an intensely vesicular, fine-grained, calcified modification of the rock. It is of pale colour owing to the high content of calcite and is sometimes stained reddish or green by iron oxides or chlorite respectively, in all cases being easily distinguishable from the from the nonvesicular rock which often rises in rounded islands from it. It seems likely that the trap represents the upper surface of the intrusion modified by carbon dioxide expelled by the high temperature from the overlying marly sediments.

In hand specimen the rock is dark, fine-grained, and shows abundant microphenocrysts of olivine, occasionally replaced by bright red bowlingite. The presence of analcite in distinct crystals is indicated by light spots on the weathered surface and small lustrous areas on the fresh face. These spots are about ½ a centimetre in diameter.

Texturally there is considerable variation. Although the actual contact of the sill with sediments is not seen, a specimen near the seaward edge showed cognate xenoliths in the form of disrupted portions of vesicular chilled edge. The extreme fineness of these portions makes it probable that they represent devitrified tachylite. Near the base and top the rock is very fine-grained. The central zone of the sill is coarser in texture and contains bands and schlieren of still larger grain-size. The latter have a texture somewhat coarser than the average basaltic groundmass and seem to have fairly abrupt junctions with the rock of the central zone. The suggestion is one of autointrusion by a late phase with slight tendency to pegmatitic growth.

Both structurally and mineralogically the central zone and its schlieren resemble one another and show appreciable differences from the finer marginal zones.

These differences include the habits of felspar and magnetite and the relative proportion of the latter mineral. On the whole the fine marginal phase is decidedly more femic than the central phases.

THE CENTRAL ZONE.

This zone contains abundant microphenocrysts of olivine of an average length of about .7mm. but occasionally reaching a length of 3 mm. They are usually entirely converted to serpentine and iron oxide but locally the pseudomorphs consist entirely of bowlingite. The latter mineral is bright red in hand specimen and in section shows pleochroism in red, yellow, and green tints. Its single good cleavage is symmetrically orientated in the pseudomorphs, being parallel to the short diameter of the lozenge-shaped section. A few phenocrysts of augite occur, showing green chrome-diopside centres and purple titanaugite margins. Occasional olivine-augite intergrowths are seen and also glomeroporphyritic aggregates of augite phenocrysts.

The groundmass contains abundant augite grains of about .1 mm. diameter and equally plentiful labradorite laths. The latter are frequently zoned, having a marginal growth of albite. Some interstitial orthoclase is present, and also fine apatite needles and scattered flakes of brown biotite. Magnetite occurs in grains up to .3 mm. diameter and showing ophitic relations to augite labradorite, and apatite. Nepheline occurs generally in small amount, but locally figures prominently in patches rich in sodic felspar corresponding probably to the segregation veins which occur in the finer-grained parts of the sill and will be described below. The nepheline is developed interstitially to the labradorite but may be seen to project into the albite borders of the laths. It may be seen in all stages of replacement by pale green chlorite, hydronephelite, and analcite. The chlorite is the most prominent of these and may have partly replaced the other two. It occurs fairly abundantly throughout the rock and may have replaced considerably more nepheline than is at present indicated. Clear, pale yellowish analcite occurs in the rounded accumulations characteristic of this mineral. These correspond to the spots seen in hand specimen, each representing a single crystal. They enclose poecilitically the augite, labradorite, magnetite, and apatite of the groundmass. In the analcite, however, the labradorite laths are slenderer and have rounded edges and sometimes embayments indicating corrosion. Apparently their more sodic zones have been partially or completely removed. Orthoclase and biotite are also absent from the analcite.

The coarser bands occurring in the central zone have a mineral content similar to the foregoing. Augite phenocrysts are however more abundant and the groundmass augite occurs in prisms of various sizes. The magnetite grains are few and have the same ophitic habit as was noted above. Nepheline is more abundant and gives rise to characteristic pseudomorphs in which yellow cloudy analcite figures prominently, associated with chlorite and hydronephelite. Analcite in somewhat smaller quantity occurs interstitially throughout the rock, showing little tendency to form the large poecilitic crystals seen in the central zone. These coarse bands thus show decided affinity to the finer-grained, "basaltic" teschenites which have been described from various localities in the Midland Valley of Scotland (Flett 1910, Tyrrell 1912, Bailey 1925, Campbell and Stenhouse 1934).

THE MARGINAL ZONES.

In the marginal zones the texture is considerably finer than in the central zone, and flow structure is frequently seen.

Microphenocrysts of olivine are accompanied by a few of augite showing deep purple colour and frequent hour-glass zoning.

The labradorite appears to be in two generations. About half occurs as laths and .2 mm. long, and the rest in much smaller microlites. Nepheline was detected in small amount and occurs more plentifully in the segregation veins described below.

The groundmass is characterised by richness in magnetite which varies in habit from abundant distinct grains to a uniform black dust. The labradorite felspars are free from inclusions of magnetite and so presumably crystallised before it.

Analcite is plentiful and occurs in distinct rounded patches enclosing augite and magnetite grains and labradorite laths. It tends to include areas free from inclusions especially in the very fine grades. It also seems to include more magnetite dust as the rock becomes finer in texture. A typical weathered surface of this rock shows the spots to occur about 100 to the square inch. They are about 1/16 of an inch diameter and may occur alone or partly fused with adjacent individuals.

Pale green chlorite is present in the groundmass in varying amount and can be observed in process of replacing felspar and analcite.

Small biotite flakes and apatite needles are always present in this phase.

The cognate inclusions mentioned above consist of small augite granules and labradorite laths in an isotropic groundmass rendered almost opaque by a dense powdering of magnetite dust. Small phenocrysts of olivine and augite are present and also numerous small vesicles filled with analcite which has in many cases been partly or wholly replaced by chlorite. These chloritic growths characteristically contain well developed biotite flakes. This type of inclusion is seen drawn out forming dark streaks in the rock.

In certain of the fine-grained slides veins are observed having irregular thickness (up to ½ mm.) and vague boundaries. As in the Chesters rock they are probably due to tension fissuring prior to the complete solidification of the groundmass. The contents of the vein support this view. They consist of sodic plagioclase, orthoclase, nepheline, and interstitial chlorite and analcite. The nepheline was the first to crystallise. It is seen in partial replacement by chlorite, but also shows decomposition to zeolite x and hydronephelite. On later widening, the vein has been infilled with spherulitic chlorite.

Scattered amoeboid patches occur in the rock. They are infilled with cloudy yellow analcite showing replacement by chlorite and are lined with albite crystals. The latter may be seen growing on the clear primary analcite as foundation and projecting euhedrally into the yellow, cloudy analcite of later crystallisation. This yellow analcite also occupies veins which may be seen to cut transgressively any of the rock constituents including the primary analcite.

(d) West Fenton Sill.

A quarry near West Fenton exposes a small sill of dark compact rock intruded into Calciferous Sandstone sediments overlying the trachyte lavas. The sill dips gently to the west and shows well-developed columnar jointing. The weathered surface shows the pale spots and the fresh face the small lustrous areas 2-3 mm. in diameter which reveal the presence of the analcite crystals characteristic of the basanites.

The rock is fine-grained and bears a general resemblance in section to the Kidlaw and finer Black Rocks types. Microphenocrysts of olivine are more abundant than in Kidlaw but the rock resembles the Kidlaw type in having many small olivines in the groundmass. The numerous small labradorite laths are generally unzoned and no interstitial orthoclase was detected. A few large xenocrysts of albite occur. As mentioned previously no chondroids or biotite flakes occur as in Kidlaw.

The pseudoporphyritic habit of the primary analcite is well developed. The mineral also occurs in streaks presumably filling tension partings analogous to those occurring in Kidlaw and Black Rocks where they are occupied by nepheline and felspar. In the present instance they were presumably opened after the crystallisation of the felspar. Apatite needles occur throughout the groundmass but are especially plentiful in the analcite. The rounded crystals of this mineral include, in addition, fibrils of ilmenite and the "segregation veins" contain a strong development of radiating fibrils of ilmenite, skeletal rods of pyroxene, dendritic flaky brown amphibole, and possibly a little biotite.

These occurrences of primary analcite may be seen to be cut through by veins of later yellow cloudy analcite showing local replacement by green chlorite. The chlorite does not seem to effect the earlier analcite so readily. This later analcite may also be seen to corrode and replace the primary mineral in the "segregation veins".

As in the Black Rocks, the marginal phases appear to be richer in magnetite, the latter occurring as a fine dust of minute granules. The base of the sill is not exposed but the lowest zone in the quarry contains abundant small xenoliths, comprising half of the rock's bulk, and probably representing a chilled phase which had suffered later brecciation. The fragments consist of a very fine-grained equivalent of the normal rock, rendered almost opaque by a dense "powdering" of magnetite dust, and containing numerous vesicles up to ½ mm. in diameter. These are filled with the clear yellowish analcite and contain centrally a dense group of its characteristic inclusions, among which the amphibole is prominent. The analcite in these vesicles must have crystallised before brecciation, as many of them have been broken across and now appear as semicircular clear areas on the edges of the xenoliths. Local replacements of the analcite by later cloudy analcite and the latter in turn by chlorite are seen.

(e) Swiney Craigs, North Berwick.

On the North Berwick shore, a few yards to the west of Swiney Craigs, an occurrence of dark fine-grained rock is exposed at low tide. The rock has well-developed platy jointing along planes dipping fairly steeply to the north-east, and shows in hand specimen the lustrous spots, in this case 3 mm. in diameter, which are characteristic of the basanites. The relations of this intrusion to the surrounding rocks are obscure. Its western margin is defined by a fault which brings against it the red Basal Ash. The eastern margin is obscured by sand and much of the intrusion itself is hidden by boulders. There are two main exposures some 30 yards apart, indicating an elongate outcrop. The columnar jointing so characteristic of the basanite sills is not in evidence, but the platy joints may represent the marginal partings of a sill. Actually they dip in the same direction as the neighbouring rocks so that if the intrusion is a sill it is emplaced in the lava succession below the mugearite of Swiney Craigs.

The section shows numerous microphenocrysts of olivine only, in a groundmass of augite granules, scattered magnetite grains of larger size then the augites, and laths of labradorite. Small biotite flakes and apatite needles are also present. The analcite which contains inclusions of iron-ore fibrils and apatite needles occurs in the customary poecilitic crystals. Much cloudy analcite is also present, sometimes with reddish staining, and partially replaces the felspar.

(f) <u>The Yellow Man Vent</u>.

The dyke cutting the Yellow Man is part of an irregular plug-like intrusion (one of several associated with this vent, Pl.IV) which shows in section the characters of a typical basanite. Phenocrysts of olivine and augite up to 3 mm. long are associated with numerous microphenocrysts of both of these minerals and also some of labradorite. The groundmass is fine-grained and contains slender prismatic augite granules, magnetite grains, and partly analcitised labradorite laths. The analcite has the usual habit. It is yellowish and partly cloudy and contains inclusions of apatite needles, ragged prisms of brown amphibole, and fine fibrils of ilmenite.

(g) <u>Garvald</u>.

At Garvald Mains farm, ¼ mile beyond the south-east extremity of the Chesters sill, a roughly oval-shaped intrusion occurs, cutting the Upper Old Red Sandstone. It is plug-like in form, having a larger diameter of $\frac{1}{4}$ mile, and gives rise to a prominent hill with a fairly abrupt western scarp. It is probably truncated on this side by the same fault which bounds the south-west side of the Chesters sill. The hill is surmounted by an ancient fort - a ponderous series of earthworks which obscure very effectively the natural exposures over much of the outcrop. Specimens from the steep western side show a dark compact rock bearing locally the familiar lustrous spots about 3 mm. indiameter. Microphenocrysts of fresh olivine and augite are also visible and sporadic large augites up to 7 mm. in diameter.

In section, the phenocrysts of olivine and augite are seen to be of various sizes up to 2.5 mm. in length. The augite shows characteristic colour-zoning and seive-structure.

The fine-grained groundmass resembles that of the finer phases of the Black Rocks in the flow-parallelism of the labradorite laths and the abundance of magnetite granules. The analcite crystals are however less distinctly defined. Under crossed nicols they appear as irregular isotropic patches and streaks in which the felspar is less abundant, presumably having been to some extent corroded. The analcite is clear and colourless and contains apatite needles and minute specks of iron ore in addition to the

the other rock constituents.

Specimens from some parts of the intrusion do not show lustrous spots and in section are seen to have a base of brown glass containing dendrites of iron-ore, and showing local replacement by analcite and chlorite. The felspathic content of this phase appears to be similar to that of the holocrystalline phase, suggesting that the glass represents largely potential analcite.

(h) Fidra.

The island of Fidra lies about $\frac{1}{4}$ mile offshore 2 miles west of North Berwick. It apparently consists of a single stock-like intrusion of irregular outline, the largest diameter exceeding $\frac{1}{4}$ mile.

The rock is in general dark-coloured and contains locally well-developed lustrous spots. Slightly coarser textures are to be observed however, as might be expected in a mass of this size, the variation being comparable to that seen in the Black Rocks. A feature of the intrusion is the occurrence of numerous sedimentary xenoliths. An analysis of the rock published by Day (1932) is quoted on p.

The section shows microphenocrysts of both olivine and augite, the olivine largely fresh. The augite of the groundmass occurs in well formed granules of larger size than is usual among these rocks. They are associated with magnetite usually in grains of comparable size but occasionally in larger plates having ophitic relations to both augite and felspar. A few small biotite flakes are also present. Analcite has the usual habit, and the interstices also contain some natrolite calcite and chlorite.

As in the Gullane sill the coarser phases show a marked resemblance to the "basaltic teschenites". The pseudoporphyritic habit of the analcite is no longer traceable, this mineral merely occupying interstitial patches as in the latter rocks. The presence of zeolites also serves to increase the resemblance. The augite proportion tends however to be higher than in the teschenites but a close genetic relationship between the two groups is indicated.

(i) Fernylee.

About 6 miles south-east of Dunbar an intrusion with basanitic affinities is encountered, associated with lava and Ash of Cementstone age. It has an elongated outcrop, extending from the neighbourhood of Oldhamstocks to the farm at Fernylee, a distance of about ¾ mile. It apparehtly cuts the volcanic rocks transgressively but exposures are very poor and so conclusive evidence concerning the form of the intrusion is lacking. Specimens taken from stream-side exposures at both ends of the mass showed no appreciable variation in composition. Considerable variation in texture was noticed however. No lustrous spots appear in any of the specimens.

The coarser phases show numerous phenocrysts of olivine and augite, the former in larger numbers, and both having an average lenght of about 1.5 mm. The augite does not show the chrome-diopside cores typical of the basanites. In the groundmass augite granules and labradorite laths are present in about equal quantity, the labradorites reaching a length of 1.5 mm. The latter mineral is locally zoned to albite, and some orthoclase is present interstitially. Fine needles of apatite also occur, and small patches of a zeolite, possibly natrolite, are fairly frequent. Analcite is present in less amount than is typical of the basanites. It differs also in habit, being colourless and cloudy and occurring in interstitial patches which show no aggregation into rounded areas. None of the inclusions characteristic of the primary analcite of the basanites are present.

The whole aspect of the rock and in particular that of the analcite is strongly reminiscent of the "basaltic teschenites". The augite occurs in larger quantity however than in the latter group. It must therefore be regarded, like the few other occurrences previously noticed, as transitional between the fine-grained pseudoporphyritic type of basanite and the "basaltic teschenite".type.

Summary of Group II.

The chief characters of the rocks of this group may be summariesd as follows:-

(a) Sufficient felspar is present to lend itself to the production of flow-structure which is well developed in several of the intrusions notably Black Rocks, West Fenton, Garvald, and Yellow Man.

(b) Local abundance of granular magnetite is noticeable in several cases, particularly Black Rocks, West Fenton and Garvald.

(c) Nepheline has been identified in accessory amount in two of the intrusions. In both of these it shows replacement by chlorite and analcite. Pseudomorphs of nepheline in these minerals must be practically unrecognisable as such and may be present, as yet unobserved, in several of the other intrusions.

(d) Pseudoporphyritic analcite is well developed in most cases. Evidence of resorption of felspar within the analcite patches has been noted. With a few exceptions the inclusions in the analcite consist only of apatite needles and some ilmenite fibrils.

GROUP III.

This group is characterised by a distinct predominance of femic minerals (mainly augite) over felsic. Felspar however is never absent.

Occurrences.

(a) Limplum, about a mile south-west of Chesters; a sill intruded into the Basal Ash of the Volcanic Series.

(b) Primrose Bank, near Seacliff (Pl.IV); a sill and two plugs, one of the latter associated with vent-agglomerate. The surrounding rocks are Cementstone sediments.

(c) Tantallon Vent (Pl.IV); a dyke-like intrusion at the southern margin of the vent; also blocks in the agglomerate of the vent which pierces Cementstone sediments.

(d) Oxroad Bay Vent (Pl.IV); blocks in the vent which pierces Cementstone ash.

(e) Dunbar coast, 1 mile east of the town; an intrusion probably a sill, in Cementstone sediments.

(f) Dunbar, the Dove Rock; a small plug piercing Upper Old Red Sandstone.

(g) Dunbar Castle; a plug-like intrusion which cuts Upper Old Red Sandstone and also traverses a vent piercing these sediments.

(h) Weak Law, $\frac{1}{2}$ mile E. of Black Rocks; a small plug piercing the trachyte lavas.

(i) Pressmennan, near Stenton; a narrow dyke in the Upper Old Red Sandstone.

(j) Whittinghame, near Stenton; an intrusion of doubtful form, possibly a sill, cutting the Basal Ash.

(k) Gin Head Vent (Pl.IV); an irregular vent-intrusion, the vent piercing sediments of Cementstone age.

(a) The Limplum Sill.

This sill constitutes what is probably the largest occurrence of basanitic rock in East Lothian. It is intruded into the Basal Ash of the Volcanic Series and lies in a syncline pitching to the south-west. the arcuate outcrop so produced extends from Limplum to Yester, a distance of about 2 miles, and finds expression topographically in an elongated ridge which is cut through at about its mid-point by a fluvio-glacial channel similar to the one seen at Chesters. In spite of its size natural exposures along the sill are few and so a full study of the rock cannot be made. Specimens taken from several points, however, show characters which justify its inclusion in the melabasanites. The points referred to include Baro Quarryon the north side of the fluvo-glacial channel; a small outcrop on the south side of the channel; a small quarry at Sheriffside Farm; and a knoll in the field just south-west of this farm.

Specimens from the the first three of these localities are dark and fine-textured in hand specimen. That of the second and also over part of the Baro Quarry exposure shows lustrous spots on the fresh face. In the fourth locality the rock is courser in texture and although it does not show a regular array of spots, scattered patches are discernible.

In section the finer-grained rocks show numerous microphenocrysts of olivine, and, in less quantity, of augite, the latter zoned from central chrome-diopside to marginal titanaugite.

The augite grains of the groundmass occur in different sizes and give the rock a characteristic aspect, larger equidimensional crystals contrasting somewhat with more plentiful smaller granules. The magnetite grains are also small, and labradorite occurs in short laths showing cloudy analcitisation. Small prisms of apatite are also present.

Three types of groundmass base may be distinguished. In one, which occurs in Sheriffside Quarry and in parts of Baro Quarry, the base consists of red-brown glass. The latter has a refractive index of 1.553 and contains dendritic growths of iron oxide with typical rectangular branching, and also slender ragged growths of a brown mineral, presumably hornblende.

In other parts of Baro Quarry and in the second outcrop listed above, pseudoporphyritic analcite in crystals 2-3 mm. in diameter is well developed and as previously mentioned appears as lustrous spots in hand specimen. The analcite is clear and colourless or pale yellowish, each crystal containing, near its outer margin only, numerous fibrils of ilmenite and some fine prisms of brown hornblende. The remainder of the base in these specimens consists of what appears to be the devitrified remains of glass. Dendrites of iron ore and ragged prisms of hornblende are present in a matrix consisting of a confused aggregate of cloudy analcite and chlorite. The clear analcite crystals may represent the reconstitution of the glass, the latter having been devitrified by hydration.

In other parts of Baro Quarry no glass is to be observed and pseudoporphyritic analcite is developed with a peculiar habit. It is yellowish and is densely crowded with the same inclusions as noted above with the addition of numerous apatite needles. No lustrous spots appear on the surface possibly because the lustre is masked by the numerous inclusions.

As compared with the holocrystalline phases the felspar content of the glassy rocks is appreciably less indicating that the glass represents potentially both felspar and analcite.

The coarser rock occurring in the fourth locality shows considerable differences in structure from that elsewhere in the sill. Both olivine and augite occur in a variety of sizes ranging from groundmass grains to phenocrysts, the former up to .5 mm. long and the latter up to 4 mm. The labradorite occurs in .5 mm. laths and is partly replaced by cloudy analcite. A little orthoclase is present interstitially. The rock is considerably more felspathic than the finer phases of the sill, felspar having increased at the expense of augite. Biotite flakes are abundant and analcite occurs both as interstitial patches where it is turbid and free from inclusions, and as larger pseudoporphyritic areas in which it is clear, yellowish, and contains the inclusionsnoted above with the addition of green pyroxene needles. These areas evidently correspond to the lustrous areas on the rock surface. Some interstitial zeolites are present suggesting the decomposition products of nepheline but no definite pseudomorphs of this mineral were detected. Nepheline has, however, been reported from Limplum by Bailey in the Memoir. This rock apparently froms another example of a structural type transitional between the fine-grained basanite characterised by pseudoporphyritic analcite and the coarser basanitic rocks which have been called "basaltic teschenites".

(b) Primrose Bank.

The occurrence of three intrusions at Primrose Bank near Seacliff (Pl.IV) was described by Day (1932). They include a plug situated in a small vent and occupying a prominent position in the inner cliff, a smaller poorly exposed plug situated on the shore to the north and possibly intruded into an extension of the same vent, and also a sill in the cliff to the south-east.

Hardened vent-agglomerate may be seen adhering to the face of the larger plug. On the west side however the igneous rock makes contact with the sandy sediments of Cementstone age. As contact alteration is not obvious it has been suggested (Barrow, in the Memoir, and Day 1932) that these sediments are younger than the intrusion, being banked against it. An examination of the cliff-section revealed considerable disturbance in the sediments immediately overlying the intrusion and the presence in several of the small faults of veins of calcareous and siliceous material and also a few thin sedimentary dykes of sandy facies. It seems reasonable to attribute the disturbance and the mineral veins to intrusion of the igneous rock into already consolidated strata. The sedimentary dykes may be of the nature of fault-rubble or they may indicate a shallow depth of cover at the time of intrusion.

The three intrusions consist of the same rock which in hand specimen is dark and fine-grained with conspicuous microphenocrysts of augite and numerous lustrous spots 2-3 mm. in diameter.

In section the porphyritic augite is seen to have the characteristic colour zoning and sieve structure. Serpentinised olivine occurs as a few microphenocrysts and also as grains in the groundmass. The augite granules of the latter are of various sizes and are associated with the usual magnetite grains and small laths of labradorite. The analcite also occurs in typical pseudoporphyritic development. Locally, limonitic pseudomorphs of the rectangularly branched dendrites typical of glass are seen embedded in chlorite, suggesting the former presence of glass occurring sporadically as in the Limplum Sill.

(c) Tantallon Vent

On the shore, at the southern margin of the Tantallon Vent (Pl.IV) the cliff-line is interrupted by a projecting scar formed by a dyke-like intrusion. The rock has a typical basanitic aspect, being dark and fine-grained and showing lustrous spots 2 mm. in diameter.

In section, the rock calls for no special comment. Porphyritic olivine and augite are present in crystals of various sizes, olivine predominating.

The groundmass resembles in composition that of the preceding occurrence except that the analcite crystals are more vaguely defined and show a tendency to merge into one another and form irregular streaks.

Blocks of a similar rock, more decomposed, were obtained from the agglomerate of the vent.

(d) Oxroad Bay Vent.

A small vent was recorded by T.C. Day (1932) near the southern apex of Oxroad Bay (Pl.IV). A large number of igneous blocks of typical basanitic aspect are to be seen in the agglomerate with which it is filled. In section these prove to be very similar to those of the Tantallon intrusion which occurs at not many yards distance on the west side of the Bay. The analcite crystals are however more clearly defined than in the latter intrusion.

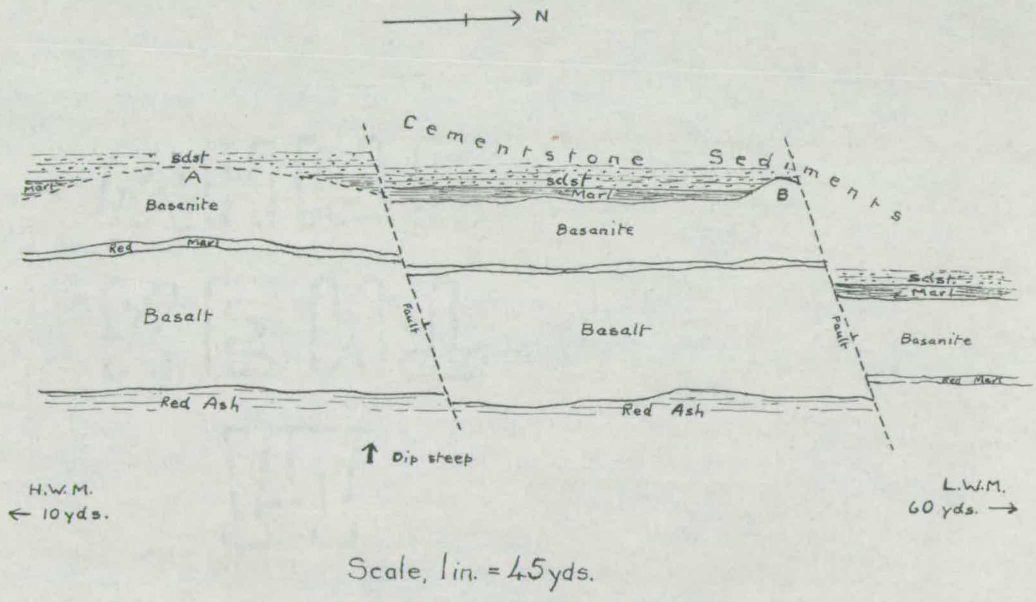
(e) Dunbar Coast.

In the East Lothian Memoir, C.T. Clough described, on the coast 1 mile east of Dunbar, "a narrow strip of igneous and sedimentary rocks belonging to the Cement-stone Group .... bounded by large faults on both sides and lying between the Upper Old Red Sandstone on the west and the Carboniferous Limestone series on the east; two bands of vesicular lava crop out here and give rise to conspicuous scars on the shore.... The sediments with which these igneous rocks occur are to a large extent composed of greenish-grey shales and fine-grained white or yellow sandstone .... Their strike is north and south and they are highly inclined towards the west. About 300 ft. of them occur on the west side of the lavas and dipping steeply over them, but it is tolerably certain they are in reversed order as are the neighbouring beds belonging to the Upper Old Red Sandstone and the Carboniferous Limestone on either side .... The upper or eastern lava is a basalt of Dunsapie type."

Clough refers to the western rock as a lava, describing its vesicular nature and also pointing out that in section it resembles the monchiquites. This statement is subsequently advanced as evidence for the early date of some at least of the monchiquitic rocks in East Lothian.

The supposition that the beds are in reversed order is confirmed by the f act that the Dunsapie lava is intensely vesicular on the eastern side and much less so on the other side, indicating that the former is the top of the flow. This lava is overlaid by red ashy sediments and is separated from the western rock by a band of red sandy marl which varies in thickness from 1 to 5 ft.

The bulk of the western rock, which has a thickness of about 12 yds., appears to be in a state of advances decomposition. It has a greenish-grey colour and shows on the weathered surface abundant pale rounded spots of about 2-3 mm. diameter, thus dis†laying the characteristic feature of the analcite basanites. A few scattered phenocrysts of about 5 mm. long are seen, and abundant microphenocrysts of the same mineral, about 1 mm. long, all replaced by red or dark greenish decomposition products. The rock



Diagrammatic Plan
Shore, 1 ml E. of Dunbar.

is affected more or less throughout its whole mass by signs of disturbance in the form of abundant interweaving cracks and fissures, filled with calcite and chlorite, and showing slickensiding along their planes. They divide the rock into "eyes" of fresher rock separated by zones of intense chloritic decomposition. The disturbance is probably associated with the local faulting. When freshest, the rock is dark-coloured, has a compact texture, and shows numerous lustrous areas of the same size as the spots mentioned above, indicating the presence of pseudoporphyritic analcite. The rock contains, locally, near the eastern (upper) margin, sinuous bands of intense vesiculation, the vesicles being filled with calcite.

The contacts at top and base of the rock-body are largely obscured by boulders and other beach deposits. Sufficient remains exposed however to show that the marly sediments at both contacts have been baked and marmorised, and locally bleached. The actual selvage of the igneous rock is decomposed to a clayey consistency. Attempts to section them proved unavailing. In hand specimen however both appear to represent chilled edges. Neither surface shows an irregular or scoriacious appearance, and the top gives no indication of contemporary weathering. The vesiculation is moreover of a local character and is more strongly reminiscent of the white-trap facies of the Black Rocks than the regular vesiculation of the lava flow such as that lying above it. It has already been mentioned that the band of marl bewteen the rocks is of various thickness. This suggests the possibility of a transgressive contact. The base of the western rock is clearly seen to pass transgressively across marls into sandstones in at least two localities (A and B in diagram). This may not be accepted as conclusive proof of transgressive intrusion, as it is not inconceivable that a lava might plough or even erode by its flowage a few broad furrows in soft sediments.

The accumulated field evidence seems to favour an intrusive rather than an extrusive character for the western rock. Petrologically it is closely related to the analcite basanites which are not known to occur anywhere in East Lothian in lava form. If the basanite magma did occur as such it might be expected that its high water-content would be manifested in more intense vesiculation than is displayed by the rock in question. At all events, the latter cannot be accepted unquestionably as a lava and hence has no value as an indication of the age of the basanites.

In section, the olivine phenocrysts are seen to be fairly well shaped and entirely replaced by serpentine and limonite. A smaller quantity of augite micro-phenocrysts is present, showing chrome-diopside interiors, often very corroded, and purplish titaniferous margins.

The groundmass contains abundant well-developed granules of augite and magnetite. The leucocratic constituents include felspar and felspathoid (nepheline and analcite) in about equal proportions. The felspar is largely labradorite in small laths .2 mm. long, showing no sodic zones. A little interstitial orthoclase was detected. The nepheline occurs in prisms up to .7 mm. long, whose boundaries are usually vaguely defined due to their ophitic relation to the femic minerals and labradorite. Smaller prisms occasionally show idio-morphic outlines against orthoclase. The nepheline thus appears to have a similar habit to that described by McRobert (1925) from Southdean. It is entirely replaced by a faintly yellowish or greenish mineral with platy development, a single crystal often occupying a pseudo-morph. A similar replacement of nepheline is described from Northern Ayrshire by A.G. MacGregor (1930). This mineral was determined as uniaxial (or pseudouniaxial) positive, with positive elongation, straight extinction with reference to a single cleavage, and a birefringence in yellow tints. Its refractive indices were found to be 1.550 and 1.561. It therefore corresponds in all respects to zeolite x as described in the Chester rock (p. 38). Sporadic biotite flakes occur in the felspathic groundmass and interstitial chlorite is present in varying amount. Analcite occurs in the familiar rounded patches representing single crystals, and enclosing poecilitically the femic minerals and labradorite. No orthoclase was seen enclosed, and nepheline only at the margin. Fine apatite needles occur throughout the felspathic and analcitic parts of the groundmass.

The amount of nepheline present is abnormal among the rocks of this group, being sufficient in this case to justify the naming of the rock a nepheline-analcite - melabasanite.

(f) Dunbar, The Dove Rock.

This is the name given to a roughly conical knoll situated on the shore about 150 yds. west of Dunbar Castle. It is formed by a small plug of dark fine-textured rock intruded into Upper Old Red Sandstone. The hand-specimen shows no lustrous spots, but vague lustrous streaks may be discerned.

The section reveals a basanitic composition resembling that of the Tantallon intrusion. Here again the analcite crystals are poorly defined and show an even stronger tendency to merge into streaks, a habit which accounts for the absence of well defined lustrous spots on the rock face.

(g) Dunbar Castle.

A prominent feature of the Dunbar coastline is a high rock, surmounted by the Castle, and rising in steep cliffs from the sea which surrounds it on three sides. This natural fortress consists of the agglomerate of a vent pierced by an elongated plug-like intrusion of dark fine-textured rock which also traverses the Upper Old Redsandstones for some distance beyond the vent margin on the landward side.

No lustrous spots are visible on the rock face. The section shows numerous microphenocrysts of altered olivine and a few of augite with typical colour-zoning, the chrome-diopside centres frequently showing an unusually bright green tint.

The groundmass augite occurs in squat granules of various sizes, and the small laths of labradorite are partly replaced by cloudy analcite. Interstitially a little orthoclase is present and a few prismatic crystals of a mineral which resembles nepheline in appearance and decomposition products. A few biotite flakes occur and also apatite prisms of similar size to the felspar laths. The analcite of the base is turbid and occurs in vaguely defined rounded accumulations 1-2 mm. in diameter. The absence of lustrous spots may be due to the cloudy nature of the mineral.

(h) Weak Law.

To the east of the vent at Weak Law (T.C.Day, 1925), a mile north-east of the Black Rocks a small plug pierces the trachytic (upper) lavas of the Volcanic Succession.

The rock specimen has the usual dark compact appearance but no lustrous spots are visible. In section an unusual aspect is provided by the occurrence of both fresh olivine and augite in c rystals of various sizes ranging from phenocrysts of 1 mm. in length to groundmass granules. The felspar occurs in laths up to .5 mm. long. The groundmass appears to be analcitic throughout. Irregular areas of clear analcite contain abundant ilmenite fibrils and apatite needles. Much of the analcite is cloudy however and effectively masks any original pseudoporphyritic structure of the clear variety.

(i) Pressmennan.

The Memoir records the occurrence of a narrow dyke in the Upper Old Red Sandstone near Pressmennan Loch about 1 mile south of Stenton. The dyke is well exposed on the banks of a stream on the hillside south of Woodend House. About 5 ft. broad it is easily distinguished from the horizontally bedded sandstones by its pronounced veritcal platy jointing.

In hand specimen the rock has the familiar dark fine-grained appearance with the addition however of a faint brownish resinous tinge suggestive of a high content of analcite. No lustrous spots are visible. Fresh olivine of pale honey-yellow colour is present in numerous microphenocrysts and also scattered larger crystals up to 5 mm. long.

In section the absence of porphyritic augite is noticeable. The augite granules are small amd are sometimes seen enclosed sub-ophitically in the scattered magnetite grains. The short laths of labradorite are associated with a little interstitial orthoclase. Apatite is present in small well-developed prisms, and a few flakes of biotite also occur.

The groundmass base consists of clear yellowish analcite associated with and partly replaced by chlorite and colourless cloudy analcite. The clear analcite contains dense aggregates of ilmenite fibrils and also "combs" of apatite needles. A suggestion of the pseudoporphyritic habit is traceable though largely obscured by the irregular distribution of the cloudy analcite and chlorite. The absence of lustrous spots may be due as in parts of the Limplum sill to the abundance of inclusions.

(j) Whittinghame.

On the steep northern bank of the Whittinghame Water, less than a mile west of Stenton, a poorly exposed intrusion of doubtful form occurs. It is situated in the Basal Ash and may be a sill but as specimens can only be obtained by digging among the tree-roots its relations to the surrounding rocks must remain obscure. The specimens obtained are somewhat decomposed and do not show lustrous spots.

Phenocrysts of olivine and augite in equal quantity are more abundant than is usual among the members of this group, and form a considerable proportion of the rock. Both occur in various sizes grading down to groundmass granules. The augite shows well-marked colour-zoning and sieve structure. The groundmass contains the usual constituents, apatite occurring in prisms of similar size to the felspar laths. Clear yellowish primary analcite occurs in rounded areas but it largely replaced by cloudy analcite and chlorite and ferruginous products which no doubt prevent its appearance in hand specimen as lustrous spots.

(k) Gin Head Vent.

The vent at Gin Head (Pl.IV) is largely occupied by an intrusion of irregular form (T.C.Day 1932). In the main it has the aspect of a plug but its western and

and northern edges have, locally, sill-like relations to the vent agglomerate and, in the eastern part of the vent, the intrusion is observed to send off into the agglomerate a subsidiary sill which is well exposed along the cliff face for about 200 yds. The intrusion is therefore probably a plug which has sent off at or near the same level several sill-like apophyses piercing the agglomerate.

Day described the rock as a monchiquite and published an analysis which is quoted on p. 109

The rock has the familiar dark compact appearance but does not show lustrous spots. Numerous microphenocrysts of altered olivine are present and, in some parts of the mass, larger crystals of this mineral up to 1 cm. in length are plentiful. In such cases the erosion of the serpentine pseudomorphs gives the rock a pitted appearance.

The section reveals the presence of a few augite phenocrysts also. The general appearance of the groundmass recalls that of the Chesters type. The felspar however occurs in small partially analcitised laths and biotite flakes are more numerous. As in several of the previously described intrusions, the groundmass base consists of clear and cloudy analcite both in patchy development. The former contains a few ilmenite fibrils and apatite needles and any pseudoporphyritic babit has been obscured by the latter.

Locally in this intrusion the felspar dwindles to an accessory amount producing a very augitic rock which is the nearest approach to a monchiquite encountered in East Lothian.

It was previously mentioned (p.48) that blocks of melabasanite of Chesters type occur in the Gin Head Vent. These resemble the rock of the intrusion in some respects as indicated above but beyond the fact that they are of earlier date than the intrusion no definite relationship between the two types is traceable. Their close association however suggests a cognate origin.

Summary of Group III.

In the groundmass of these rocks, since augite is the most abundant mineral, its granular habit forms the dominant structural feature and so flow structure is, at the best, poorly developed. The concentration of magnetite grains seen on several occasions in the previous group is no longer encountered. Nepheline has an irregular distribution and appears to be absent in most. Its former presence in accessory amount is again a possibility however. Biotite flakes are present in most of the melabasanites and apatite frequently occurs in well-developed prisms up to .5 mm. in length. In several of the occurrences in this group the pseudoporphyritic habit of the analcite if either conjectural or poorly developed. This effect, as has been explained, is partly due to replacement by later analcite and chlorite. Still it cannot be coincidence that so many examples should occur among the less felspathic rocks. It may be that augite has increased at the expense of both felspar and primary analcite. Another occurrence of a type transitional to the basaltic teschenites has been noticed in this group. An intrusion consisting entirely of such a rock now falls to be described.

GROUP IV. GLASSY ROCKS.

Two instances have already been noticed (Garvald and Limplum) in whcih the groundmass base of a basanitic intrusion is locally glassy. It was suggested that in the former the glass represents potential analcite and, in the latter, potential analcite and felspar.

A few other glassy intrusions occurring in East Lothian show a strong resemblance, in section, to the above rocks and are probably therefore of similar composition. They occur at Cheese Bay, Longskelly Rocks, and Yellow Man Vent.

Along the shores of Cheese Bay within the distance of a mile north of the Black Rocks, three small sills occur intruded into Upper Calciferous Sandstone sediments. The most northerly forms the promontory of Eyebroughy Scar. Each shows well-developed columnar jointing and is dark and fine-grained in specimen. Again, just over a mile east of Eyebroughy a plug is seen intruded into the Longskelly Vent (Day 1932). Two plug-like intrusions occur at the western side of the Yellow Man Vent (Day 1927).

In s ection these rocks have a typical basanitic aspect except that the base consists of brown glass and the felspar occurs in relatively smaller quantity. Microphenocrysts of labradorite are, moreover, present in the Yellow Man Rocks. The absolute quantity of the femic minerals is comparable to that of the basanites of Group II and is considerably greater than that of the type Hillhouse basalt to which these rocks otherwise bear a strong resemblance. The glass typically contains the same inclusions noted in the Garvald and Limplum rocks, namely, dendrites of iron ore, ragged prisms of brown amphibole, and sometimes a few needles of apatite. In the Longskelly plug the glass is remarkably free from inclusions, a few iron ore dendrites being the only representatives. This rock was photographed by Day who also published an analyses, quoted on p. The resemblance between the inclusions of the glass and those of the primary analcite of other basanites lends support to the theory that the former has a composition approximating to that of unhydrated analcite. No common value for the refractive indices of the glasses could be found, those of Limplum and the most southerly Cheese Bay sill for example having values of 1.553

and 1.526. Both of these are however considerably greater than the index for analcite (1.490).

Chemical analyses of specimens from the most southerly Cheese Bay Sill and the Longskelly Rocks are quoted below. Comparison with the other analyses listed shows a close similarity to the basanites of Group II of this division, thus increasing the probability that these glassy rocks and also those others mentioned above are of basanitic composition.

	1	2	3	4	5	6	7	8	A	B
SiO_2	42.46	40.71	42.02	42.69	43.05	43.64	44.22	44.61	42.49	46.2
TiO_2	2.57	3.94	2.75	2.07	2.63	2.98	2.70	2.32	2.51	2.5
Al_2O_3	13.06	14.08	14.19	11.45	14.23	16.57	13.78	17.76	13.85	13.8
Fe_2O_3	6.43	6.53	1.04	4.09	4.00	3.87	5.26	2.21	2.59	1.9
FeO	7.10	6.83	9.98	7.61	7.07	6.91	7.02	8.78	9.32	9.3
MnO	.24	.23			.17	.32	.40	.18	.29	.1
MgO	8.68	6.86	10.65	13.64	8.62	6.29	7.51	6.40	11.21	9.5
CaO	10.66	12.01	.0183	10.37	10.55	9.76	8.71	10.12	9.76	10.0
Na_2O	2.77	2.29	2.82	2.37	2.36	2.09	4.38	3.32	2.39	2.5
K_2O	.84	1.80	.59	.77	.98	1.86	1.77	1.35	.87	1.7
H_2O −105°C.	.90	.30)				1.94	.34		.47	.3
		)	4.58	3.80	4.65			2.28		
H_2O +105°C.	3.26	3.22)				2.98	2.83		3.35	.7
P_2O_5	.62	.76	.79	.76	.82	.42	1.18	.71	.61	.4
CO_2	Tr.	Tr.	.11	.14	1.18	.06	.37	.11	.22	.6
FeS_2	.26	.27			.28	.27		.21		.1

1. (Division A). Chesters Normal Rock. (New Analysis). Analyst, W.H. Herdsman.

2. do. Chesters, Extreme Permeation Phase. (New Analysis). Analyst, W.H. Herdsman.

3. do. Leithies laccolith. Analyst, T.C. Day.

4. (Division B, Gr.III) Gin Head Intrusion. Analyst, T.C. Day.

5. do. Gr. IV) Most southerly sill, Cheese Bay. Analyst, T.C. Day.

6. do. Gr. IV) Longskelly Rocks. Analyst, T.C. Day.

7. do. Gr. II) Kidlaw Intrusion. Analyst, E.G. Radley.

8. (Division B, Gr.II). Fidra. Analyst, T.C. Day.

A. Olivine basalt of Hillhouse type; Sill, Hillhouse Quarry, near Linlithgow, W. Lothian. Analyst, E.G. Radley.

B. Olivine basalt of Dalmeny type. Lava, Quarry 230 yards south of Dalmeny Church, W. Lothian. Analyst B.E. Dixon.

Discussion of Analyses.

The differences between the analyses of the Chesters Normal Rock and the Extreme Permeation Phase may be interpreted as follows, analysis (2) being discussed with comparative allusions to analysis (1).

SiO_2 decreases and Al_2O_3 increases in spite of an increase in alkali felspar, (reflected in a higher K value), and a disappearance of calcic plagioclase. These are explicable when the increased proportion of nepheline is taken into account. The Na value undergoes little change however, increase in nepheline being offset by loss of plagioclase. A notable feature is the decrease in MgO with respect to CaO which actually shows a considerable absolute increase. The loss of MgO is due to diminution if not disappearance of olivine, and the gain in CaO may be explained by the increased importance of augite and also, possibly, by the appearance of amphibole. Increase in TiO_2 is to be expected in view of the higher titanium content of the augite and probably also the iron ore. Similarly increase in apatite in the extreme phase produces a rise in the P_2O_5 value.

The Gin Head analysis (4) shows a notable decrease in Al_2O_3 and increase in MgO with respect to the other melabasanites. Of these two changes, the former may be ascribed to the diminution in felsic material and the latter to the larger proportion of olivine for which the rock is notable.

The resemblance of the analyses of the glassy rocks (5) and (6) to the analyses of the basanites (7) and (8) strengthens the probability that these rocks are closely akin to the basanites. The close correspondence in the water contents in particular would seem to indicate that much of the glass is probably potential analcite.

The transition from melabasanite to basanite is marked by a rise in both SiO_2 and Al_2O_3 due to increased proportion of felspar. A slight decline in MgO reflects the relatively smaller importance of olivine. CaO and total iron do not vary much as, though augite decreases, lime-felspar and magnetite increase.

A strong similarity exists between the analyses of the melabasanites and that of the Hillhouse basalt (A), suggesting a close affinity between these two types. The Dalmeny basalt (B) shows a lowered water content and an increased silica value as compared with the basanites, both being changes which are compatible with a reduction in analcite and an increased proportion of felspar.

C. LEUCITE-BASANITES (INCLUDING KULAITES).

In 1936 D. Balsillie described the first leucite-bearing rock to be reported from the Scottish Carbo-Permian Province. It is a leucite-basanite and forms two small plugs in the Car Vent (Pl.IV) and in section (Pl.VIII.3) shows microphenocrysts of augite with some olivine and scattered large hornblendes, in a groundmass of leucite, augite and magnetite granules and plagioclase laths, together with some analcite and glass.

Among the slides prepared by T.C. Day, who described the vent (1932) one of the ash shows fragments of a fine-grained modification of the basanite. Though these are highly decomposed, the leucites, pseudomorphed by analcite, remain relatively clear and preserve their shape and characteristic inclusions (Pl.IX.3).

In a few other rocks of East Lothian the presence of small rounded, hexagonal or octagonal structures composed of analcite and containing the zoned inclusions characteristic of leucite was noticed. They resemble exactly those of the Car Vent and as Balsillie has pointed out present the same appearance as those occurring in continental leucite-bearing rocks. In many of the laths and also in cases reported from other parts of the world particularly America the leucite is also completely replaced by analcite, and the question has been raised by Washington (1914) and others as to whether leucite did actually exist in these rocks. The occurrences of the mineral in East Lothian are, naturally, open to the same doubt. Before discussing this question however, accounts of the different rocks concerned will be given

<u>Occurrences</u>:-

(a) North Berwick; leucite-kulaite lavas.

(b) North Berwick, the Lecks shore; blocks of leucite-basanite in an agglomerate bed.

(c) Garvald Mains; a loose block of leucite-melabasanite.

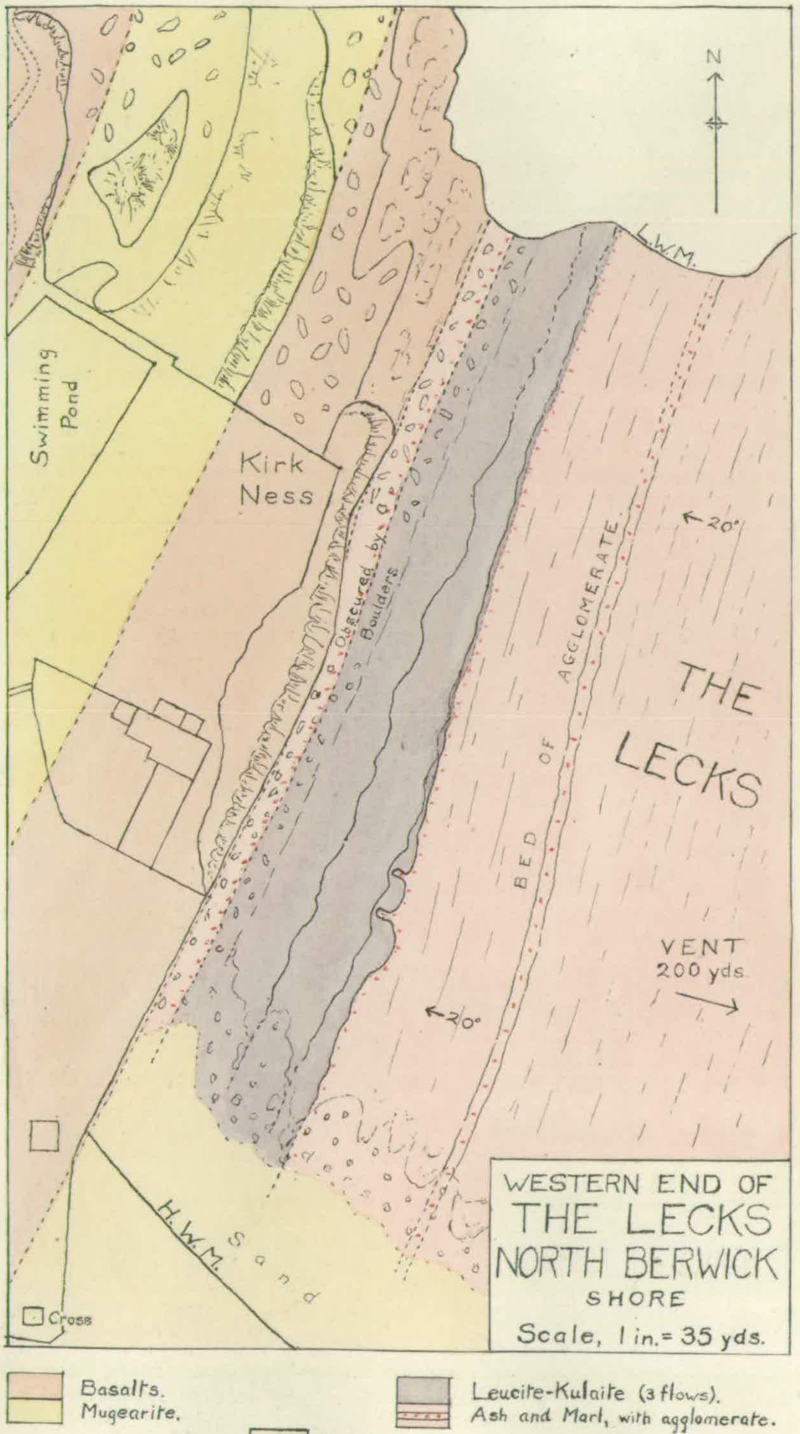
(d) The Yellow Man Vent; a block of leucite-basanite in the vent agglomerate.

(e) Traprain Law; inclusions containing pseudoleucites.

(a) Leucite - Kulaite Lavas, North Berwick.

A brief account has already been given (p. 43) of the rocky stretch, known as the Lecks, on the North Berwick shore. It was mentioned that the red ash dips towards the north-west and is overlaid by the lavas which form the promontory at the harbour. In the Memoir, mention is made (pp. 71-72) of a thin greatly decomposed lava flow interbedded in the ashy sediments and occurring a few yards to the east of the outcrop of the main mass of lavas. An examination of the area revealed the presence of three thin lava flows occupying a band 20-30 yards broad (Pl.VII) and separated from the overlying lava pile by about 3 yards of sediments consisting of red ashy marl with a basal agglomerate layer about a yard thick. A similar bed of agglomerate occurs below the lavas, both beds containing fragments a few inches in diameter of the same material as the lavas. No sedimentary intercalations occur between the flows, though the upper surface of the second flow in particular shows reddening due apparently to contemporaneous weathering. All three flows are highly vesicular throughout except for a thin band of less vesicular rock near the base of each. These bands have a variable thickness, that of the lowest flow seldom exceeding 1 ft. while that of the second flow reaches locally a thickness of 3 ft. The topmost flow

Pl. VII


N
Swimming Pond
Kirk Ness
Obscured by Boulders
L.W.M.
← 20°
BED OF AGGLOMERATE
THE LECKS
VENT 200 yds
← 20°
H.W.M.
Sand
Cross
WESTERN END OF
THE LECKS
NORTH BERWICK
SHORE
Scale, 1 in. = 35 yds.
Basalts.
Mugearite.
Leucite-Kulaite (3 flows).
Ash and Marl, with agglomerate.
Sand

is peculiar in possessing hexagonal columnar jointing perpendicular to the plane of dip. The vesicular nature of the lavas render them little more resistant to deundation than the red ash and so they rise but slightly above the general level of the rocky flat. The base of the lowest lava is very uneven and consequently, levelling of the shore has exposed the underlying agglomerate in several embayments in the outcrop. Moreover, the lowest flow, in the northern part of the outcrop is exposed only on the side of a small gully which follows the strike. This flow is about 1 yard in thickness, the others being both about 3-4 yards thick. The vesicular portions of each are dark red in colour, with paler calcarious vesicles, and are greatly decomposed. The less vesicular bands are considerably fresher and hand specimens from the three flows have an exactly similar appearance.

The rock is fine-textured and has a dark purplish tint with, locally, reddish streaks where alteration is more advanced. Locally, also, the rock is mottled by pale greenish yellow spots of various sizes, apparently representing the effects of bleaching. Microphenocrysts of prismatic hornblende occur up to 3 mm. in length. They may be black or dark red in colour or contain a streaky mixture of light and dark products, according to the different degrees and modes of alteration.

In section, the lavas are so closely similar that a single description will suffice.

The structure (Pl.VIII. 2) is microporphyritic, the most abundant phenocrysts being idiomorphic prisms of hornblende showing almost complete conversion to granular titaniferous magnetite which, in turn, has locally decomposed to a dendritic intergrowth of limonite and leucoxene. Remnants of the original amphibole have been replaced by green chlorite and a peculiar light brownish serpentine. This mineral is associated with some light coloured cloudy material, probably leucoxene. Both together are responsible for the light streaks in the hornblende prisms noticed in hand specimen. The hornblendes reach a length of 2.5 mm. and a diameter of over .5 mm. Their resorption with precipitation of magnetite must have occurred before the crystallisation of the felspar as this mineral is seen to occur interstitially to the iron ore granules in the pseudomorphs. The hornblende encloses prisms of cloudy apatite up to .2 mm. in diameter. These have rounded, somewhat irregular outlines, as if they had undergone corrosion. Similar stout prisms, generally about .5 mm. long occur scattered throughout the groundmass.

A smaller number of olivine phenocrysts are represented by pseudomorphs of limonite, colourless serpentine, pink chlorite and calcite.

Idiomorphic augite phenocrysts are represented by pseudomorphs having the typical eight-sided section and consisting mainly of brownish serpentine and limonite.

Granitic xenocrysts, including fragments of quartz, orthoclase, microcline and oligoclase occur sporadically throughout the rock.

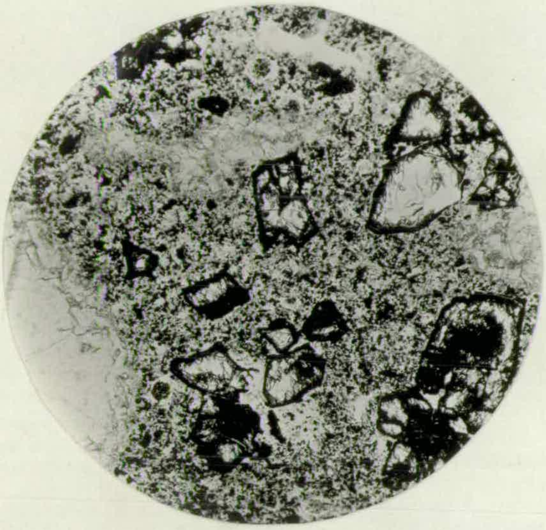
The fine-grained groundmass, which is in a considerably decomposed condition consists of leucite, plagioclase and granular augite and magnetite. A few needles of apatite and some interstitial analcite, chlorite, and limonite are present. The augite is represented by small pseudomorphs consisting of material similar to that in their counterparts among the phenocrysts. Granular magnetite is fairly abundant and is largely converted to limonite. The felspar consists of abundant small laths of a plagioclase having a refractive index which corresponds to oligoclase-audesine. The crystals frequently have a narrow zone of albite marginally. A little orthoclase occurs interstitially.

The leucite appears in the characteristic rounded sections up to .3 mm. diameter (Pl.IX No.2). In specimen from the middle of the lava flow the leucite is found to be approximately equal to the felspar in bulk, while in the less vesicular zone near the base it occurs in somewhat smaller proportion. It contains inclusions of numerous dark specks arranged in concentric rings and wreaths, typically surrounding a dense central group. Small microlites of felspar are also included especially near the margin, and are orientated tangentially. Occasionally, octahedral arrangement of the inclusions is seen. The leucite has been entirely replaced by a clear faintly yellowish analcite of refractive index 1.490. Colourless or brownish analcite, usually cloudy, occurs interstitially to the minerals of the groundmass. It contains fine apatite needles and is associated with some chlorite and ferrite.

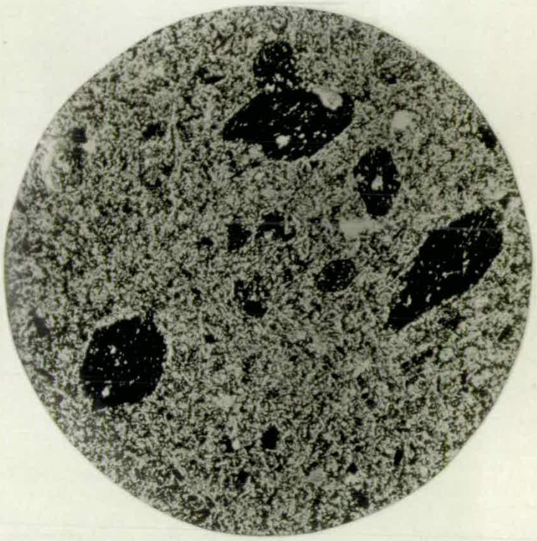
A few slides of the Blaikie Heugh kulaite (described by Bailey in the Memoir) were examined and for purposes of comparison with the Lecks rock one of approximately equal grain size was selected. This slide shows the true kulaitic character of distinct predominance of hornblende over augite, a condition which is not obvious, if it exists at all, in some of the coarser specimens of this rock.

A striking similarity to the Lecks rock is at once apparent. The hornblende however is in slightly larger proportion and shows occasional remnants of the fresh mineral, but otherwise corresponds in every respect to that of the Lecks rock. Its association with cloudy apatite and the occurrence of this mineral in the groundmass are also identical. Again, the groundmass minerals and their development are strikingly similar in both rocks. In particular, the occurrence in the Blaikie Heugh rock of numerous small leucites of similar size to those of the Lecks is noticeable. Here also

Pl. VIII



1.



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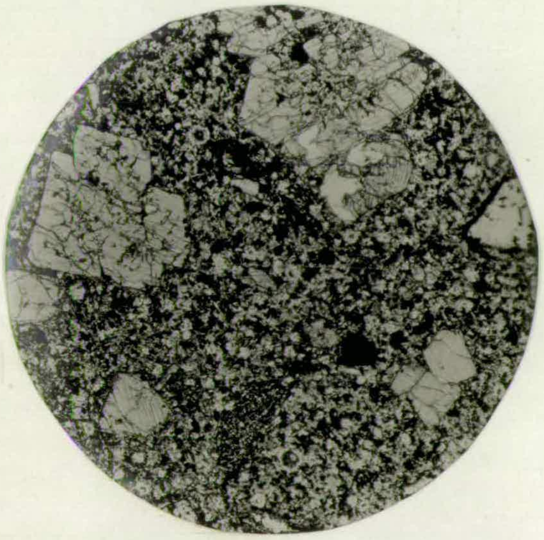

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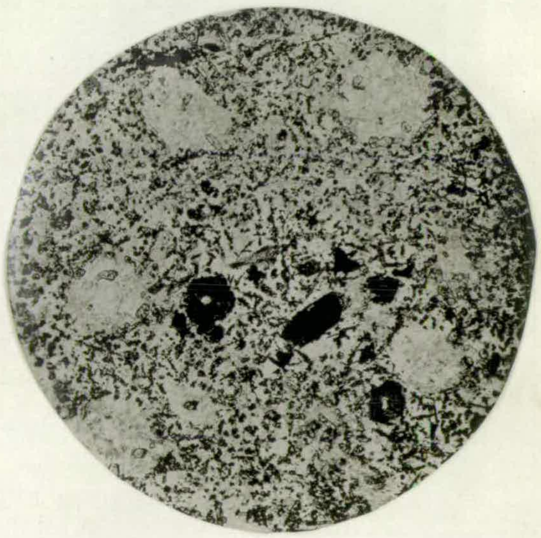


4.

Explanation of Plate VIII.

1. (Ordinary light x 40). The Lecks, North Berwick. Leucite-basanite block in agglomerate band.

Phenocrysts of olivine altered to serpentine and limonite. The light areas are calcite-filled vesicles. A few leucites may be seen in the fine grained groundmass.

2. (Ordinary light x 40). The Lecks, North Berwick. Leucite-kulaite lava.

Porphyritic hornblende (dark) with included apatite prisms (upper central phenocryst). Indistinct outlines of altered microphenocrysts of augite on upper margin (to the right) and in upper left quadrant (2 crystals). A few of the small leucites of the groundmass are distinguishable (as in part of lower field). Pl.IX.2. photographed from this slide.

3. (Ordinary light x 20). Leucite-Basanite, Car Vent (Balsillie 1936).

Phenocrysts of augite, and (on right) of olivine. Numerous round light spots in groundmass are leucite. A good example occurs between the two phenocrysts on the upper left.

4. (Ordinary light x 15). Traprain Law. Xenolith (or autolith).

Phenocrysts (dark) of fresh hornblende. Rounded light areas are possible pseudoleucites and consist of orthoclase and nepheline in intimate intergrowth. A few laths of hornblende occur in the groundmass but most of the dark rods are augite prisms with included magnetite grains.

the mineral has been replaced by analcite but the zonal arrangement of the inclusions is still preserved though not in such perfection as in the Lecks lavas. Incidentally these leucite pseudomorphs are to be seen in larger size but more scattered occurrence in the coarser kulaite specimens from the same locality. In many of these the zoning of the inclusions has been obviously partly destroyed during the replacement by analcite and hence it is possible that the visible pseudomorphs may represent only a part of the original leucite content. These pseudomorphs are doubtless those referred to as possible pseudoleucites by Bailey.

It appears therefore that the Blaikie Heugh rock is in part at least a true leucite-kulaite and by analogy it is proposed to apply this name to the Lecks lavas also, although in absence of fresh material the true proportions of hornblende and augite can only be roughly determined.

(b) North Berwick,
The Lecks.

Mention has already been made (p. 43) of a band of agglomerate occurring in the ash of the Lecks at North Berwick, and containing blocks of ash and igneous rock. The band outcrops about 30 yards east of the kulaite lavas (Pl.VII) and is about 2 yards thick. The ash of the blocks closely resembles that of lower horizons in the Lecks. The igneous blocks occur in various sizes up to 1 ft. in diameter and do not have the structure of bombs.

The rock is fine-grained and is seldom free from vesicles, some specimens being highly vesicular (Pl.VIII.1.). The freshest specimens are dark coloured with a purplish tinge and show numerous somewhat elongated microphenocrysts of olivine altered to a red-brown substance. Some specimens are light buff or greenish in colour and are seen in microsection to be intensely calcified and chloritised. Their aspect both in specimen and section recalls that of the bleached spots in the kulaites as in both cases the dark ferruginous matter in the groundmass has been completely removed.

In section, the olivine microphenocrysts which average .5 mm. in length show well-formed outlines, little resorption being evident. Their tendency to elongated development has already been mentioned. Sporadic large olivines up to 5 mm. long occur also. The mineral is completely replaced by pale green or yellow-brown serpentine, the pseudomorphs having a border of limonite. It therefore resembles both in habit and alteration the development of the phenocrysts in the Lecks Vent plugs. Augite microphenocrysts occur in smaller numbers. They are frequently perfectly euhedral and are replaced by calcite.

The groundmass is of fine texture and bears a close resemblance to that of the leucite-kulaites of the Lecks. The numerous small laths of felspar have a refractive index corresponding to oligoclase-audesine, the laths being bordered by narrow zones of more sodic composition. Leucites are present (Pl.VIII,1) with the characteristic inclusions. They tend to be slightly larger and less frequent than in the kulaites, and, as in the latter are completely replaced by analcite. The remainder of the groundmass consists of augite granules replaced by calcite and chlorite, magnetite grains represented by limonite specks, numerous fine needles of apatite and a considerable number of biotite flakes. Analcite, chlorite and ferruginous matter occupy the interstices.

The rock is therefore a leucite-basanite and appears to have distinct affinities to the leucite-kulaites of the same neighbourhood. Blocks of this basanite occur also in the Lecks Vent and lapilli of the rock are to be found at various levels throughout the red ash both in the Lecks (where the agglomerate band marks its highest occurrence) and in the exposures near Point Garry, half-a-mile to the west. Its presence in the vent is of doubtful significance. The blocks are few and may possibly have originated by disruption of previously formed agglomerate. In the absence of an extrusive or intrusive representative, the origin of the rock must remain obscure. It can only be inferred, from the wide distribution of the lapilli both horizontally and vertically, that it emanated from a volcano of important size - the source of much if not all of the local red ash.

It is interesting to note that this third volcanic occurrence of leucite is also among the earliest manifestations of Carboniferous Volcanic activity, being in fact older than the leucite-kulaites in the North Berwick district at least.

There is some evidence to support the suggestion that the agglomerate band in the Lecks owes its origin to the activity of the nearby vent. The contents in both are of similar material, igneous blocks being, however, more numerous in the band. The origin of the blocks themselves would have to be attributed to the disruption of a small vent plug or minor crater-flow of lava. They are too numerous to be accounted for by disruption of lower block-bearing zones and as they have not the structure of bombs they must have formed parts of some previously solidified rock-body.

In the account of The Lecks Vent on p.43 , a row of foundered blocks was described as lining its western margin. Moreover the blocks had to a certain extent consolidated though it was pointed out that no long interval separated their deposition and disturbance. The date of the vent's final explosive activity is limited in another direction when it is considered that its agglomerate contains no blocks of kulaite or of any of the overlying lavas. It is therefore permissible to conclude that the explosive activity had ceased before the extrusion of the kulaites. Thus, even supposing that the agglomerate band in the Lecks did not exist, the converging lines of evidence outlined above would indicate its approximate horizon as that at which the final explosions of the vent occurred. Also the possibility must not be overlooked that the band represents the entire explosive activity of the vent. Incidentally, as the vent plugs are of later emplacement, the above evidence limits in one direction the date of this occurrence of the Chesters type of melabasanite.

(c) <u>Garvald Mains Boulder</u>.

A loose block occurring on the steep western side of the basanite outcrop at Garvald Mains was found in section to contain structures resembling small leucites.

Numerous microphenocrysts of fresh olivine and augite are present, both occurring in various stages. The groundmass consists of augite granules also of different sizes, associated with labradorite laths, both of these minerals occurring in melabasanite quantity. Abundant small magnetite grains are also present. Nepheline occurs in minor amount in plates up to 1 mm. long, having poecilitic relations to the minerals mentioned above. A little alkali felspar occurs interstitially and biotite flakes up to .5 mm. in diameter and also with poecilitic habit are fairly frequent, giving the rock a distinctive appearance.

Fairly numerous small clear areas occur, having central groups and rings of inclusions and occasionally showing six- and eight-sided outlines. They occur typically in clusters and consist largely of analcite of refractive index 1.490. Euhedral outlines against alkali felspar and possible also nepheline may be detected. The mineral may also be seen enclosed in biotite flakes. Many of these small individuals, which probably represent leucite crystals, have apparently been rounded by resorption, others are seen to contain remnants of an isotropic mineral of higher refractive index than the analcite and which possibly represents traces of the original leucite.

Texturally the rock resembles more the finer holocrystalline Limplum types than the Garvald rock. More magnetite is present however than in the former locality, the content and habit of this mineral closely resembling its occurrence in the latter intrusion. Boulders of the Chesters rock were discovered in close association with the erratic in question, so that ice-transport from a western (i.e. Limplum and Chesters) direction is indicated. Its origin is by no means established however and so, in absence of better exposures of both Limplum and Garvald intrusions, must be left in doubt.

(d) <u>The Yellow Man Vent</u>.

Among the microsections in the T.C. Day collection placed at my disposal, one of a block from the agglomerate in the Yellow Man Vent merits some description.

Microphenocrysts of olivine and augite are present in a groundmass of augite granules, labradorite laths and abundant small magnetite grains. The olivine, augite and labradorite have been replaced by calcite and chlorite. The groundmass contains much orange-red cloudy analcite which may be seen to form hexagonal prismatic pseudomorphs sometimes euhedral against and sometimes intergrown with albite, and which therefore probably replaces nepheline. The remainder of the groundmass is occupied by clear yellowish analcite which contains small clear areas characterised by zoned inclusions (Pl. IX.1) and bearing a strong superficial resemblance to leucite crystals. No definite outlines were detected and a refractive index determination gave the value 1.490.

Except for the leucite, the rock appears to resemble in composition some of the more nepheline-rich modifications of Chesters, but owing to its decomposed state, its affinities cannot be determined with any accuracy.

(e) Traprain Law Inclusions.

The phonolite laccolith of Traprain Law contains, besides occasional xenoliths of sedimentary rocks (Day and others), fairly numerous inclusions of a dark igneous rock. The latter occurs as rounded masses up to 1 ft. in diameter or as streaks drawn out parallel to the pronounced flow-banding which is a feature of the phonolite. These streaks frequently exceed 1 yard in length.

The rock of these inclusions is seen in hand specimen to contain scattered phenocrysts of sanidine up to 1 mm. in length and also a few black prismatic micro-phenocrysts. The most noticeable feature however is the presence of numerous rounded white or pinkish spots of an average diameter of 2 mm. Several of these show distinct six-sided outlines, others being oval in outline due to flow.

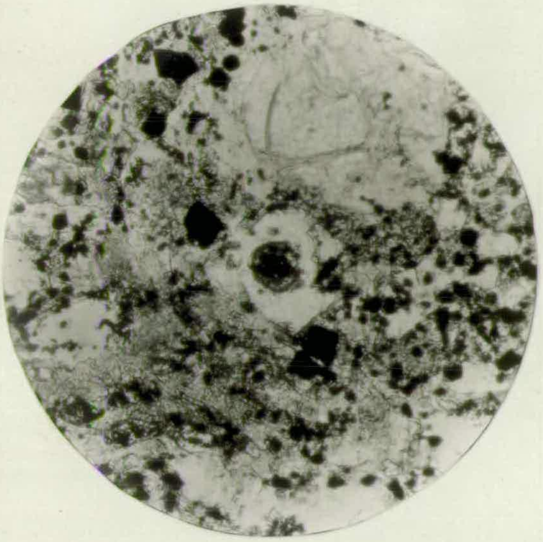
In section, the rock (Pl.VIII, 4) is seen to be moderately fine-grained. The large mineral constituents include, besides the phenocrysts of sanidine already alluded to, several syenitic aggregates of orthoclase, albite and some aegirine-augite, a few large prismatic pyroxenes up to 4 mm. long, scattered grains of magnetite .5 mm. in diameter, and prisms of brown hornblende up to 5 mm. in length. The pyroxene has the extinction angle of ordinary augite but has pleochroism from pink to green. Both it and the hornblende enclose large cloudy apatite prisms up to .2 mm. in diameter, which also occur scattered through the groundmass. The hornblende occurs typically in clusters of prisms which are seen in all stages of replacement by pale green augite, this process involving also the precipitation of magnetite grains which are enclosed in rows in the ragged prisms of the augite.

The matrix of the groundmass consists of small interlocking plates of soda-orthoclase associated with a little nepheline analcite and sodalite, the latter showing occasionally a pale blue tint. The ferromagnesian minerals comprise a few hornblende prisms showing partial replacement by augite and magnetite, occasional partly corroded prisms of fayalite, a few biotite flakes, and numerous somewhat ragged prisms of pale green augite associated with, and enclosing in the manner described above, abundant granules of magnetite. When the abnormal habit of the augite is considered this association with magnetite can have but one significance namely, that these augites replace prisms of hornblende, the process being illustrated in the alteration of the hornblende phenocrysts.

The numerous light spots are seen in section to consist of rounded areas sometimes bounded by imperfect six- and eight-sided outlines and occupied by intimate intergrowths of orthoclase and nepheline. The interdigitate structure typical of pseudoleucites is commonly developed. Occasional green augite and fayalite crystals are enclosed marginally, the former sometimes occurring as radiating needles growing from the surrounding rock. The nepheline is partly decomposed to analcite and thomsonite or zeolite x. When the composition of these structures is considered along with their shape, uniform size, and even distribution throughout the rock, it seems that they must almost certainly be true pseudoleucites.

It is difficult to trace the affinities of these inclusions. In some cases at least they were in a plastic state in the molten phonolite so that ample opportunity was afforded for considerable reconstitution of their contents. It appears that they once possessed a content of hornblende comparable to that of the kulaites or of certain of the lamprophyres. The felspar of the original

Pl. IX.



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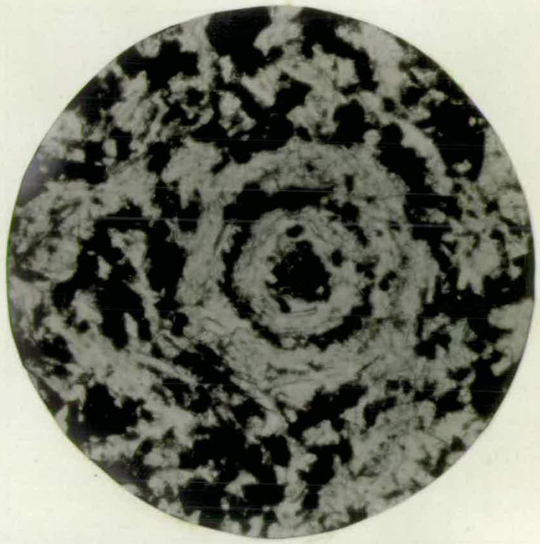

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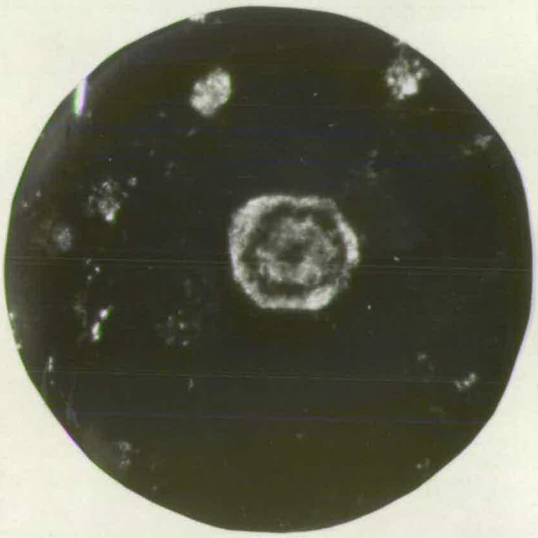

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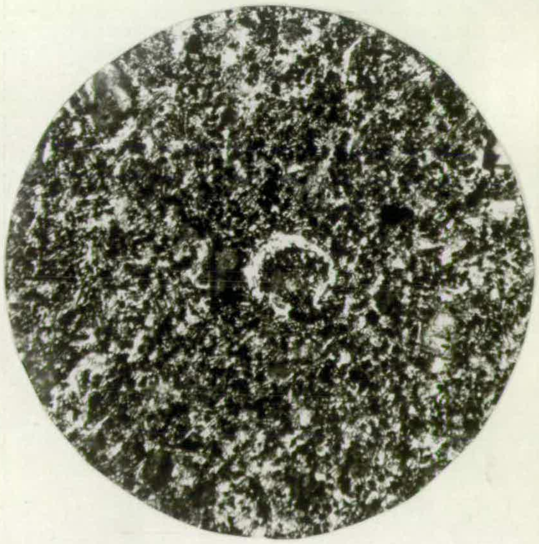

4.

Explanation of Plate IX.

1. (Ordinary light x 230). Yellow Man Vent. Block of leucite-basanite.

Centre, leucite crystal with zoned inclusions and imperfect outline, pseudomorphed by analcite. Upper olivine phenocryst replaced by calcite. Groundmass of granular augite and magnetite.

2. (Ordinary light x 230). The Lecks, North Berwick. Leucite-kulaite lava.

Leucite crystal (Pseudomorphed by analcite) showing hexagonal outline and zoned inclusions. The dark zones contain abundant magnetite specks. Small labradorite laths, tangentially arranged, may be seen in the clearer area.

3. (Ordinary light x 230). The Car Vent. Fragment of leucite-basanite in ash).

Euhedral leucite pseudomorph in greatly decomposed fine-grained basanite.

4. (Ordinary light x 80). Kidlaw Plug. Marginal zone.

Typical analcite crystal with central leucite-like structure. The latter in this case occupies half the diameter of the analcite.

groundmass, unless it already consisted of alkali felspar, was probably entirely replaced. The small fayalites may be original in which case affinity to the phonolite is indicated. The presence of large sanidine phenocrysts supports this as does also the high potash content indicated by the leucites. The large hornblendes might also be mentioned in this connection as certain phases of the phonolite such as that developed at Hairy Craig contain large hornblendes associated in the same way with cloudy apatite. Incidentally, Bailey reports from this locality "certain zeolitic patches with a concentric zonal arrangement of felspar microlites". These have not been investigated further but the description strongly suggests pseudoleucite. It is possible therefore that these inclusions are cognate xenoliths or autoliths, their parent body having been disrupted during the injection of the phonolite. Some affinity to the kulaites and hence a genetic relation between these and the phonolite is also suggested.

<u>Discussion</u>.

Considering appearance alone, the "pseudoleucites" in the above occurrences resemble very closely the habit of leucite as displayed in German, Italian, and American leucite-bearing rocks. For purposes of comparison, a study was made of the leucite in certain Bohemian and Neapolitan lavas. In some cases the crystals of the mineral were well-formed occurring as clear circular areas with numerous minute inclusions grouped in central clusters, concentric rings or in radiating formation. In other rocks it was noticed that only about one in ten of the leucites had the characteristic form and zoning. The rest, owing to the sub-ophitic relations they bore to the other groundmass minerals particularly augite, had a sub-circular aspect and often contained very few vaguely orientated inclusions. In other rocks, again, the rounded remnants of partly resorbed leucites, sometimes devoid of inclusions appeared as small clear patches embedded in the felspar. On the above standards, the leucites of the Blaikie Heugh and Lecks kulaites, the Lecks basanite, and the Car Vent are on the average exceptionally well-formed while those of the Garvald and Yellow Man blocks and the Kidlaw plug are no more imperfect than the average continental occurrence. Thus, as far as form is concerned there is no objection to the structures in these rocks being leucites.

Again, in many of the Continental and American rocks, the leucite has been replaced by analcite leaving the arrangement of inclusions unaffected. It has been shown (Lemberg and others) that this change is readily effected at temperatures of 180-195° C. by solutions of the chloride or carbonate of sodium. Thus, as there must be a fair probability of these conditions being fulfilled in a cooling lava or small intrusion it is not surprising that in so many "leucite" occurrences the alteration has occurred. Cross (1879) and Washington (1914), in accounts of such cases from Colorado and Sardinia respectively point out that potash in the rocks is shown by analyses to occur in totally insignificant amount as compared with the quantity represented by the pseudoleucites. On these grounds, they suggest that the analcite originally crystallised in the semblance of leucite, the fresh condition of the rocks being held to preclude the possibility that replacement had taken place. As regards the disposal of the potash, however, the latter might easily be removed by the liquor which is responsible for the change. The very existence of abundant analcite is a rock testifies to the former presence of much sodic aequeous liquid. Moreover the potash is not wholly removed but is incorporated in varying small amount in the analcite. The fact therefore that analcite occurs in a rock in the form of numerous leucitohedrous forms no indisputable grounds for doubting that leucite itself once occupied these structures.

Another possibility, namely that these leucite-like pseudomorphs crystallised originally as an intermediate mineral in the leucite-analcite isomorphous series, has been suggested by Washington and others. In the light of recent work by Larsen and Buie this possibility must be envisaged in connection with the occurrence of pseudo-porphyritic analcite in the basanites, in particular that of Kidlaw. It was mentioned (p. 59) that in the narginal phase of this rock, the analcite crystals contain a leucite-like structure at the core. In these structures a central knot of inclusions is invariably present (Pl.IX, 4) and hexagonal sections are not infrequent. A noticeable feature is the gradual loss of definition with increasing coarseness of rock texture. A parallel instance may be that reported from Rathjordan in Ireland by Prior (1910). The rock concerned is one of the Limerick suite and belongs to the same province and period as the East Lothian rocks. It contains phenocrysts of olivine augite and felspar in a groundmass of augite and magnetite grains with a base of clear analcite. The latter contains small scattered areas containing zoned inclusions and resembling leucites. Moreover these areas are sometimes seen to be separated from the surrounding analcite by a distant octagonal outline although the composition of the mineral inside and beyond the pseudomorph is apparently identical. No mention is made in the paper of pseudoporphyritic analcite crystals or gradations in distinctness of these structures. This case cannot therefore be cited as an exact parallel to that of Kidlaw and may even belong to the category of true pseudoleucite-bearing rocks. The rock is, however, similar in many respects to the East Lothian basanites and is therefore cited here as a possible analogous instance of the feature under discussion. This feature is not susceptible of such a simple explanation as that given for the other occurrences of pseudoleucite described above. The impression created is that the graded series of structures, in the Kidlaw rock, from typical leucitohedron to vague analcite crystal, represent the traces in varying degrees of preservation of the earlier member (or members) of a reaction pair (or series). It is generally accepted that an isomorphous series exists of which the end members are leucite and analcite. The fact that analcite is hydrated forms no obstacle since Friedel (1896) has demonstrated that water does not constitute an essential part of the crystalline molecule, the latter being similar to that of leucite. Analcite is also known to contain varying small proportions of potash. The existence in nature of other intermediate members of the series was unknown until Larsen and Buie (1938) published an account of the occurrences of potash analcite in the Highwood Mountains. The mineral is described as "a clear glassy potash analcite which has the form and appearance of leucite but lacks twinning and has a refractive index of 1.493." Analysis shows 4.5% K_2O. Since all low temperature analcite is poor in potash and it is known that potash and soda replace each other to a greater extent at high temperatures, these authors conclude that potash analcite is a high temperature product. The mineral is rarely found fresh and is seen to decompose to a cloudy amorphous material and orthoclase. In the same paper, reasons are given for suspecting the existence of other analcites still richer in potash.

This discovery reveals that both the refractive index of analcite and its power to orientate inclusions rise with increasing content of potash. It also indicates that in certain circumstances, notably the presence of water, therternary system silica-nepheline-kaliophilite contains an analcite field. The temperature relations of potash and soda analcites are not clear, but possibly include several discontinuous reactions points.

It is suggested that the structures in the Kidlaw rock are due to the previous crystallisation of an analcite slightly richer in potash than that now seen in the rock. This mineral, exerting a stronger crystal "character" concentrated and controlled its inclusions in the manner of leucite. When the temperature fell to a certain point more sodic analcite was precipitated and resorption of the potassic mineral commenced. In the centre parts of the rock-body there was sufficient time for complete resorption of the latter mineral with removal of any structural traces of its presence. In the more quickly cooled marginal zones the sodic analcite was precipitated upon the earlier mineral before the latter had been resorbed, thus preserving in all degrees of completeness the leucite-like structure. Subsequently the "imprisoned" mineral was replaced piecemeal by the sodic analcite in the same manner as leucite is replaced.

As regards the chemical possibility of the occurrence of leucite in these rocks, little can be said in the absence of chemical analysis and also in view of the alterations in composition of the rock, notably the apparent removal of much of the potash of the leucite, since the latter mineral crystallised. As far as can be estimated however, the rocks lie within the compositional limits imposed by various investigators chiefly Washington (1907) and Bowen (1928).

In conclusion, the remark of Balsillie, that it is not unlikely that other occurrences of leucite would be reported from Central Scotland, may be endorsed with a fair degree of confidence. In such an alkaline suite of rocks a wider distribution of this mineral might be expected. The fact that it has not been more often reported may be due to a tendency to occur in one or more of the "unobtrusive" modes previously mentioned as characterising some of the leucite occurrences on the Continent.

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Acknowledgements.

In conclusion, I should like to acknowledge my indebtedness to Dr. R. Campbell for many helpful suggestions and criticisms, and to Professor T.J. Jehu for placing at my disposal the T.C. Day collection of slides and specimens, now the property of Edinburgh University. My thanks are also due to Dr. R.M. Craig for assistance in the photography, and to the Trustees of the Clough Memorial Fund for a grant to defray the cost of two analyses.